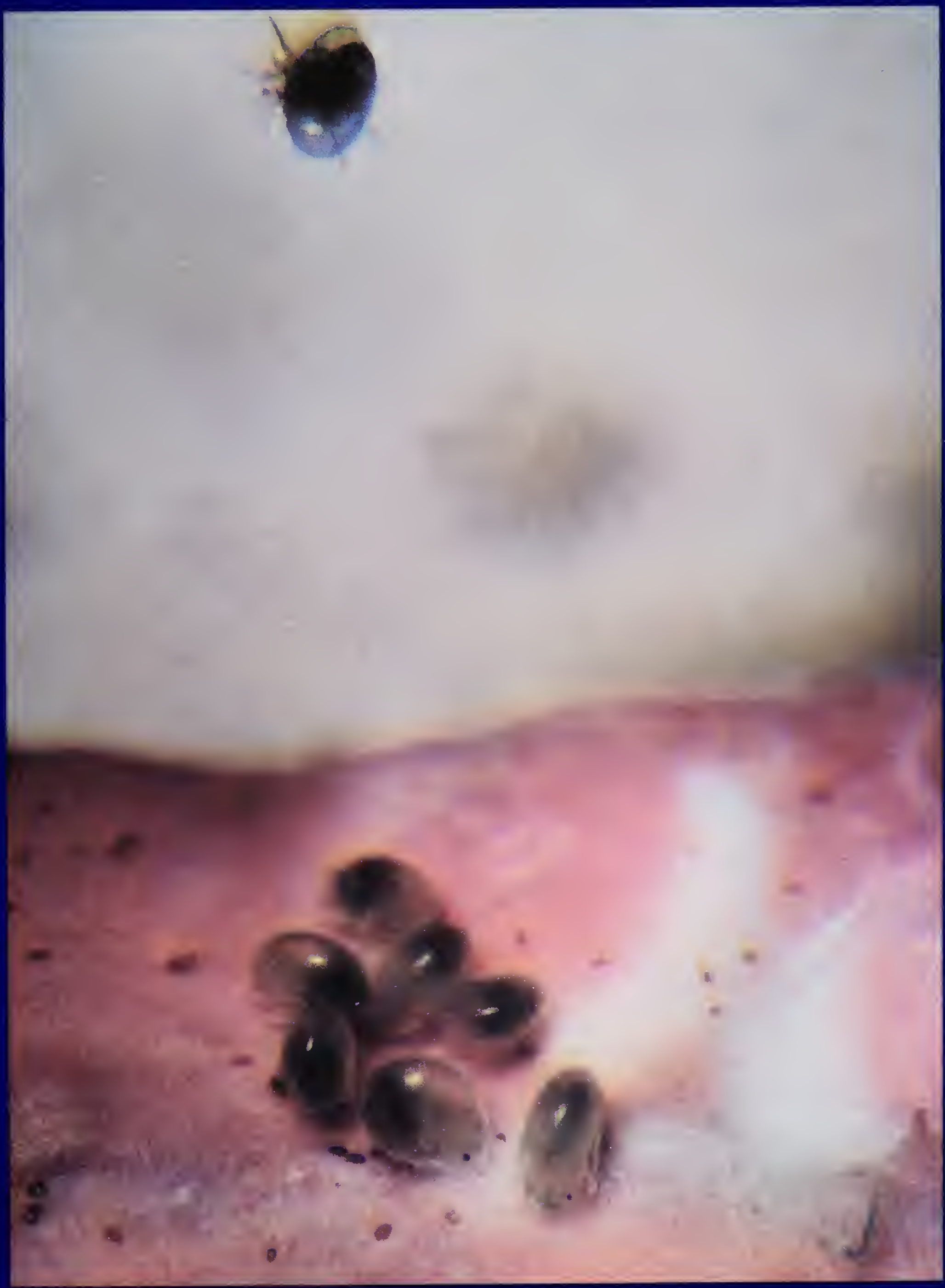
Oceanus®

Volume 31, Number 3, Fall 1988



SEA GRANT

Education, Research, Advisory Services

Oceanus®

ISSN 0029-8182

The International Magazine of Marine Science and Policy
Volume 31, Number 3, Fall 1988

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

Published by the Woods Hole Oceanographic Institution

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Editorial correspondence: *Oceanus* magazine, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543. Telephone (508) 548-1400, extension 2386.

Subscription correspondence, U.S. and Canada: All orders should be addressed to *Oceanus* Subscriber Service Center, P.O. Box 6419, Syracuse, N.Y. 13217. Individual subscription rate: $22 a year; Libraries and institutions, $50. Current copy price, $5.50; 25 percent discount on current copy orders for 5 or more; 40 percent discount to bookstores and newsstands. Please make checks payable to the Woods Hole Oceanographic Institution.
Subscribers outside the U.S. and Canada, please write: *Oceanus*, Cambridge University Press, The Edinburgh Building, Shaftesbury Road, Cambridge CB2 2RU, England. Individual subscription rate: £20 a year; Students, £17; Libraries and Institutions, £37. Single copy price, £9. Please make checks payable to Cambridge University Press.
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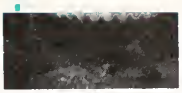

Robert Sisson, see article beginning on page 37, "Learning from Larvae"). BACK COVER: A selection of logos from various Sea Grant programs.

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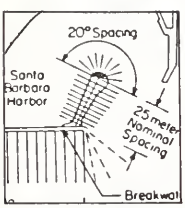
contents



COVER: A swimming planktonic abalone larva (0.2 millimeters long), looking somewhat like a fanciful alien spaceship, comes in for a landing among newly settled siblings on a red alga surface (Photo courtesy of Robert Sisson, see article beginning on page 37, "Learning from Larvae"). BACK COVER: A selection of logos from various Sea Grant programs.

 Oceanus (ISSN 0029-8182) is published in March, June, September, and December by the Woods Hole Oceanographic Institution, 93 Water Street, Woods Hole, Massachusetts 02543. Second-class postage paid at Falmouth, Massachusetts; Windsor, Ontario; and additional mailing points. POSTMASTER: Send address changes to Oceanus Subscriber Service Center, P.O. Box 6419, Syracuse, N.Y. 13217.

comment

Changing the Watch

Fred Golden *Your editor*

Photo by Rob Brown

Your editor has received a Fulbright Scholar Journalist Award to do a research project for the next nine months in Japan. I'm leaving the helm for the next three issues to Fred Golden, an experienced science writer and editor. I met Fred for the first time this summer when he was a Science Writing Fellow at the Marine Biological Laboratory in Woods Hole. You will be in good hands. The chances are you have already read some of his work without knowing it. Fred has written more than 20 cover stories for *Time* magazine, including the ones on the moon landings, the first test-tube baby, and the machine of the year (the personal computer).

Fred holds a B.A. from New York University and an M.S. from the Columbia University Graduate School of Journalism. He is the author of four books—*The Moving Continents* (1972), *Quasars, Pulsars and Black Holes* (1976), *Colonies in Space* (1977), and *The Trembling Earth* (1983). From 1984 to 1987, he was Assistant Managing Editor at *Discover*, where he was responsible for that magazine naming *Titanic* explorer Robert Ballard as 1986 Scientist of the Year.

For my part, I will be doing a study of Japan-United States marine interests in the Pacific region, with specific attention to relations with China and the Soviet Union. The core of my project is to identify where U.S.-Japan marine policies are in conflict, where they are serving joint interests, and to make an analysis of how these findings impact both nations from political, scientific, and technological points of view. While on this Fulbright, I hope to develop two issues of *Oceanus* devoted to marine affairs in the Pacific, where, by the year 2000 approximately 50 percent of the world's Gross National Product may be produced.

My base of operations while on the fellowship will be at the Japan Marine Science and Technology Center, which is located about an hour and a half from Tokyo (see Japan and the Sea, Vol. 30, No. 1). My hope is that I will be able to visit both China and the Soviet Union. After 12 years at *Oceanus*, this experience should serve to recharge my mental batteries. By the same token, Fred will bring a fresh eye to the magazine and its content, a process that can only benefit you—the readers. **—Paul R. Ryan**

Foreword:

The Halcyon Days of Sea Grant

by Harold L. Goodwin, and Robert B. Abel

On 17 October 1966, President Lyndon B. Johnson signed into law the National Sea Grant College and Program Act of 1966, Public Law 89–688. Reduced to its essentials, the law prescribed that the National Science Foundation should design and conduct a national program whose goal was to make the oceans more productive in the service of people, the nation, and the environment.

We have since been advised by legislative specialists that Public Law 89–688 was probably the last of its kind, in that it gave almost unlimited freedom to the implementing agency. Since the National Science Foundation, of all Federal agencies, generally has permitted the most freedom of action to its personnel, it goes without saying that we were relatively unfettered in designing the processes through which the Act finally was implemented. About the only guidelines available were the transactions of a one-day conference held the previous year at the University of Rhode Island, keynoted by the greatest of phrase-makers, Dr. Athelstan Spilhaus, who had first used the term, "Sea Grant," in a speech to the American Fisheries Society.

While the House and Senate bills were wending their ways through the committee processes, guided by Spilhaus, Bob Abel was invited by Senator Claiborne Pell of Rhode Island, sponsor of the bill in the upper house, to participate in the executive sessions. Further, he had been assigned by Ed Wenk, Executive Director of the National Council on Marine Resources and Engineering Development, to follow the legislative process and assume responsibility for advising the executive branch on the matter. He was doubly fortunate in thus having two sponsors to back him as a principal participant in the negotiating sessions between representatives of the Senate and House staffs and the Office of Management and Budget. While the OMB people were not wildly enthusiastic, they also were not very negative.

When the time came for Abel to present his analysis to the council, chaired at the time by Vice President Hubert H. Humphrey, he was told that the OMB representative would probably shoot the program down. To everyone's surprise the only remark from William Carey of OMB was that the program should be heavily structured and carefully controlled. As is now recognized, this is the way we designed it.

Maximum Support, Minimum Interference

Bob Abel and his secretary, Sammy Sisson, opened for business at the National Science Foundation on February 20, 1967. The question, naturally, was how to make a beginning. Hal Goodwin was recruited immediately, and was followed a few months later by Bob Wildman and Art Alexiou. It is impossible to give enough credit to the National Science Foundation. "Maximum support and minimum interference" is the dream of every administrator, and it was the basic NSF management philosophy. They taught us how to start and carry out the administrative technicalities of a program, but left program methods and content entirely to us. Most remarkable, and perhaps unique in a Federal agency, we were told – and this is a direct quote – "Don't be afraid to take chances."

Absence of guidelines and restrictive supervision allowed a large degree of creativity. Since no one told us what a Sea Grant College was supposed to be, we came up with what was later described in the trade press as the "merit badge" system, offering successive levels of: Project Support for single projects, Coherent Project Support for several projects with a common goal or theme, Institutional Support for a fully developed program of research,

education, and advisory services; and Sea Grant College status, awarded for continuous excellence of performance toward Sea Grant goals.

The techniques of the Sea Grant Marine Advisory service were developed largely by practitioners of the extension service system developed by the Land Grant Colleges and the U.S. Department of Agriculture, including such leaders as Bill Wick of Oregon State University, Walter Gray of the University of Rhode Island, Bruce Wilkins of the State University of New York/Cornell, and Greg Heddon of the University of Wisconsin.

Sea Grant policy was guided by a remarkable National Advisory Board of senior scientists, engineers, and businessmen, chaired for the first decade of Sea Grant by Dr. Sanford Atwood, President of Emory University. Not only did these busy seniors advise and review, they also commented on major proposals and participated in site visits to proposing universities.

The Communicators

One of Sea Grant's most unusual evolutions began with an energetic breed of people, mostly young women, who – for lack of a more descriptive name – came to be known as communicators. They combined the talents and experience of educators, advisory service agents, administrators, and public relations people. These dedicated people emerged more or less independently among the various institutions and fell naturally into the roles of expediters, proposal developers, community organizers, and liaison points between Sea Grant institutions. Before long they were organized into a loose confederation by Linda Weimer at the University of Wisconsin and Leatha Miloy at Texas A&M. They soon recognized the strength inherent in unity, and formed highly productive working arrangements among themselves.

The communicators were really the forerunners and stimulators of the elaborate networking system that finally became Sea Grant's most productive hallmark. While it is commonplace today for advisory service people, business and financial types, economists, and even research scientists with broadly shared interests to work together, this practice more or less originated with the Sea Grant Communication Network, a quite informal and unstructured system.

At the heart of the Sea Grant Program was the strangest creature to be born of the Sea Grant's rather unusual multifaceted requirements: the Sea Grant Director. Each institution had one. The director was our person on campus, and the institution's person in Washington D.C. He or she had to combine audacity, the persistence of a glacier, and the diplomatic skills of a Machiavelli in order to impose the requirements of the national Sea Grant Program on fiercely independent academics, to persuade researchers in both the natural and social sciences to reorient their thinking to the kinds of problem solving Sea Grant sought, and to nudge educators toward the environment and especially the world of water. The directors fought us in Washington on behalf of their programs, and fought in their universities for program recognition and the one-third matching funds the Act required. It is impossible to praise these directors too highly, especially in the program's early days. It was they who imparted a sense of genuine partnership between their programs and the Washington office, a partnership later endorsed and funded by many state legislatures that recognized value for the buck.

Those were halcyon days indeed. We could not seem to do very much wrong, and even the OMB examiners seemed to like us. At least they said nice things and permitted healthy program growth.

Into the Zero-funding Vortex

President Nixon's Reorganization Plan #4 of 1970 created the National Oceanic and Atmospheric Administration by sweeping together aquatic programs throughout the government. Into the vortex was drawn Sea Grant. Responding to an offer by the (then) Director of the National Science Foundation, Abel, Goodwin, Wildman, and Alexiou decided to remain with NSF. This announcement drew fire from a number of sources at all levels, culminating with strong words from a White House staffer who said we had to move with the program to NOAA—that President Nixon was well aware of the program and wanted it to grow, and our duty was to stay with it. We moved.

The move brought us under the purview of a new set of OMB examiners, those of the Department of Commerce. The very next budget cycle gun-decked us despite NOAA's Administrator Bob White's valiant defense, and the process continues, with determined efforts to kill the program by zero-funding it. Only equal determination by the Congress which created us has enabled the program to survive and even grow – although not to its potential. This is a matter of record.

The rest is modern history.

Harold L. Goodwin is Marine Extention Coordinator for South Carolina Sea Grant. Robert B. Abel is Sea Grant Director for New Jersey Marine Science Consortium.

Foreword:

The Mature Years

by Ned A. Ostenso, Director
National Sea Grant College Program

Hal Goodwin and Bob Abel opened this issue with a prologue looking back to the halcyon days of Sea Grant's youth. Let me say a bit about our mature years. Between youth and maturity is the inevitable turbulence of adolescence: the evolution of identity, building of strength, and shaping of personality. Going from the cared-for to the caring, Sea Grant has not been immune to these stresses, both internally and from the public we serve. Approaching age 22, (our first year of funding was 1967), we are ready to meet the world of change and challenge as an adult.

Our acquired identity is one of purposefulness and comprehensiveness. Sea Grant research adds to knowledge not for itself, or to advance a discipline, but rather to enhance the wise use and protection of the oceans and their resources. We achieve these goals by the application of many talents from diverse fields for sustained periods of time. By way of example, development of a cultured hybrid striped bass industry requires the efforts of geneticists, microbiologists, chemists, engineers, economists, lawyers, and so on, all contributing their essential pieces to a complex puzzle.

The strength of Sea Grant is that we have committed ourselves to overcome the traditional boundaries that exist between disciplines and that separate discovery from application. These barriers are formidable indeed, being institutionalized in the university (departments), government (budget line-items) and our very language (basic vs. applied). We draw further strength from the recognition that local, regional, national, and international problems all feed from the common trough of insufficient understanding. These problems are inseparable, and amenable to a common cure—knowledge.

Ned Ostenso

Our personality has been shaped by a collegial process that permeates the system—from internal to external advisors at both local and national levels, to consortia of marine extension agents, to networks of communicators, fiscal officers and lawyers, to symposia and workshops of scientists. Many voices to be heard, and a listener for all. But when advice has been heard and views aired, the time for action comes. It must be responsive and responsible. While solving problems and capitalizing on opportunities, Sea Grant cannot become a repair shop or service station. Rather, we must be mindful of our responsibility to the future rather than be preoccupied with the present. How else would we know that the solution to ocean pollution lies in microbiology, or the cure for wheat fungal disease lies in crab waste?

Because we choose to deal with complex problems, we are hard to pigeonhole neatly. Because we choose to rule by reason rather than rote, we appear untidy to the martial mind. Such is our fate.

Introduction:

Sea Grant—A National Investment for the Future

by David A. Ross

The National Sea Grant College Program works on a simple premise: Apply the intellect of U.S. universities and research institutions to the problems and opportunities associated with the use of the oceans, especially our coastal oceans. The program is the principal academic effort in the United States focusing on marine resources. Sea Grant is special in other ways, including its three-part emphasis on research, advisory services, and education, and its encouragement of cooperation between industry, academia, and the government. In addition, the program's impact on the nation's marine economy has been substantial. A 1981 analysis* showed that a fraction of Sea Grant's total project activity had led to $230 million in annual gross revenue or savings, resulting in better utilization and efficiencies in marine and coastal-based industries. This annual dollar amount is close to the *total* federal support Sea Grant received in its first 13 years. The program has never received more than $42 million in funding for any given year.

Much of Sea Grant's strength lies in its grass roots support, which is driven largely by the practicality of its research and advisory efforts. Simply said, Sea Grant research attempts to show us both how best to use the ocean, and how best to preserve it—not an easy task.

Despite the demonstrated need and value of the Sea Grant Program, it has had considerable budgetary problems during this decade. For the last seven years, its budget essentially has been eliminated by the federal Office of Management and Budget (OMB), but fortunately has been restored by Congress each year.

The future of the National Sea Grant College Program is uncertain; the program must be responsive to the needs of coastal states, local constituencies, federal budgets, national problems, and the direction of marine science. One important ray of hope lies in the most recent congressional reauthorization of the program (1987), which introduced a new concept for Sea Grant: Strategic Research Initiatives. This concept, combined with related efforts in other governmental agencies, could result in major changes in the way we view and study the oceans and could lead to very exciting times for Sea Grant.

This article offers some details about the founding and structure of the Sea Grant Program and some speculation on its future. The other articles that comprise this issue describe specific and innovative aspects of various Sea Grant-sponsored activities.

Creating the National Sea Grant Program

The National Sea Grant College Program was established in 1966 to foster understanding, development, utilization, and conservation of marine resources through support of research, education, and advisory services. Now in its third decade, Sea Grant continues to carry out that mission. Since its modest beginning, the program has grown to a base of 29 core institutional programs (Table 1 and Figure 1). In earlier years programs were located at major, marine-oriented universities and institutions. As Sea Grant expanded, it drew in other universities and institutions not part of the traditional marine community, several of which focus on the Great

* Report prepared by the Sea Grant Task Force, Washington, D.C., March 1981, for the Marine Affairs Committee of the National Association of State Universities and Land Grant Colleges.

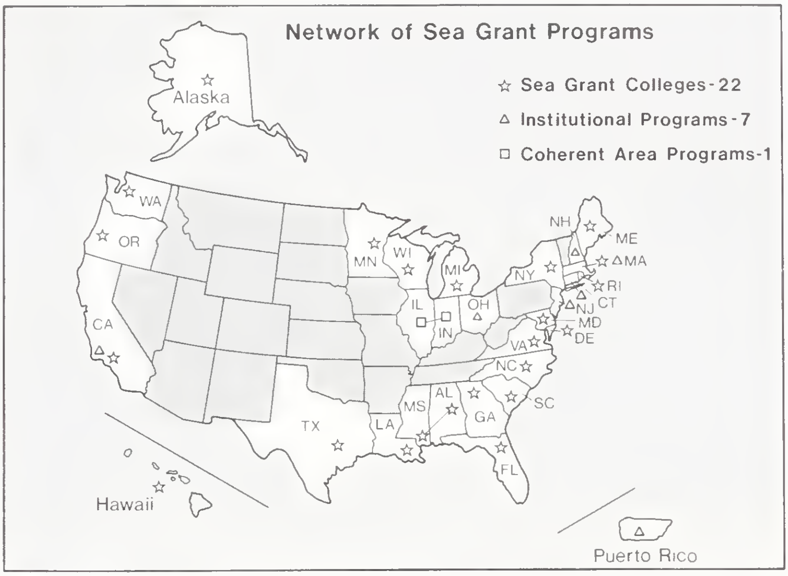


Figure 1. The three legs of the Sea Grant Network—research, education and training, and advisory/extension services—comprise more than 300 individual participating academic and marine research institutions. More than 3,000 scientists, engineers, educators, advisory/extension service agents, and students work in Sea Grant.

Lakes. Now, the Sea Grant network encompasses more than 300 universities and affiliated institutions involved in Sea Grant projects, generally working within the 29 core programs.

The term "Sea Grant" needs some clarification. First, there is a National Sea Grant Office in Rockville, Maryland, whose principal charge is to provide national direction, leadership, and coordination for the individual programs (Table 1). The present director of the national office is Ned A. Ostenso who, following a distinguished career at the Office of Naval Research, joined Sea Grant in 1977. He succeeded the first director of the national program, Robert B. Abel, who is now president of the New Jersey Marine Sciences Consortium. Then there are the 29 individual Sea Grant programs. Each individual program also has a director or coordinator who is charged with administering and leading his or her respective program as well as cooperating with other programs and sharing results across the entire suite of programs.

The origin of Sea Grant is attributed to a well-known marine innovator, Athelstan Spilhaus (see *Oceanus*, Vol. 30, No. 4, pp. 99–104). In a 1963 address on the state of the U.S. fishing industry, he asked:

> *Why, to promote the relationship between academic, state, federal, and industrial institutions in fisheries, do we not do what wise men had done for the better cultivation of the land a century ago. Why not have 'Sea Grant colleges?'**

Spilhaus, in his inimitable manner, continued to pursue the Sea Grant idea on many fronts. The concept also was advanced by John Knauss (see profile, page 75) at the University of Rhode Island, who organized a symposium on the subject in October 1965. The concept became a reality with the strong and inspired leadership of Senator Claiborne Pell of Rhode Island, who introduced Senate Bill 2439 to create Sea Grant Colleges, and Congressman Paul Rogers, who introduced the companion House Bill 16559. In October 1966, President Johnson signed a revised bill creating the National Sea Grant College and Program Act (Figure 2). The events leading up to the creation of Sea Grant are well chronicled in an account by John Miloy.*

After an initial four-year period within the National Science Foundation, in 1970 the Sea Grant Program moved to the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce. Presently, Sea Grant resides in NOAA's Office of Oceanic and Atmospheric Research, along with other extramural programs. Because of its different formula, and hence, different mindset from other federal programs, Sea Grant has sometimes appeared, in an administrative sense, to be an unwanted orphan in Washington. This has always intrigued, and occasionally disturbed me because the Sea Grant concept is basically sound, has very strong congressional support and endorsement, and has proven its effectiveness during more than 20 years.

The Three Parts of Sea Grant

The strengths of the National Sea Grant College Program lie in its conceptual underpinnings, as formalized in the Sea Grant Act. It combines

* A. Spilhaus, 1972, *Land is Just an Island*, EOS, Vol. 53, No. 5, p. 572.

* J. Miloy, 1983, *Creating the College of the Sea*, Texas A&M Sea Grant Program, 64 pp.

Table 1. Sea Grant programs. The National Office of the National Sea Grant College Program is located at 6010 Executive Boulevard, Rockville, MD 20852.

ALASKA

Alaska Sea Grant College Program
138 Irving II
Fairbanks, AK 99775

CALIFORNIA

California Sea Grant College Program
University of California
La Jolla, CA 92093

USC Sea Grant Program
Institute for Marine and Coastal Studies
University of Southern California
University Park
Los Angeles, CA 90089–0341

CONNECTICUT

Connecticut Sea Grant Program
Marine Sciences Institute
University of Connecticut
Avery Point
Groton, CT 06340

DELAWARE

University of Delaware
Sea Grant College Program
Robinson Hall
University of Delaware
Newark, DE 19716

FLORIDA

Florida Sea Grant College Program
Building 803
University of Florida
Gainesville, FL 32611

GEORGIA

Georgia Sea Grant College Program
University of Georgia
Ecology Building
Athens, GA 30602

HAWAII

Sea Grant College Program
University of Hawaii
Marine Science Building
Room 102, 1000 Pope Road
Honolulu, HI 96822

ILLINOIS/INDIANA

Illinois/Indiana Sea Grant Program
Purdue University
Department of Forestry and Natural Resources
W. Lafayette, IN 47907

LOUISIANA

Louisiana Sea Grant College Program
Center for Wetland Resources
Louisiana State University
Baton Rouge, LA 70803

MAINE

UME Sea Grant College Program
University of Maine
14 Coburn Hall
Orono, ME 04469

MARYLAND

University of Maryland
Sea Grant College Program
H. J. Patterson Hall
College Park, MD 20742

MASSACHUSETTS

Sea Grant College Program
Massachusetts Institute of Technology
Building E38–330
292 Main Street
Cambridge, MA 02139

Sea Grant Program
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

MICHIGAN

Michigan Sea Grant College Program
University of Michigan
2200 Bonisteel Boulevard
Ann Arbor, MI 48109

MINNESOTA

Minnesota Sea Grant College Program
University of Minnesota
116 Classroom-Office Building
1994 Buford Avenue
St. Paul, MN 55108

MISSISSIPPI/ALABAMA

Mississippi-Alabama Sea Grant Consortium
703 East Beach
P.O. Box 7000
Ocean Springs, MS 39564–7000

NEW HAMPSHIRE

UNH Marine & Sea Grant Programs
Marine Program Building
University of New Hampshire
Durham, NH 03824

NEW JERSEY

New Jersey Sea Grant Program
New Jersey Marine Sciences Consortium
Building 22
Fort Hancock, NJ 07732

NEW YORK

New York Sea Grant Institute
State University of New York
Stony Brook, NY 11794–5000

NORTH CAROLINA

UNC Sea Grant College Program
Box 8605
North Carolina State University
Raleigh, NC 27695–8605

OHIO

Ohio Sea Grant Program
The Ohio State University
1314 Kinnear Road
Columbus, OH 43212–1292

OREGON

Sea Grant College Program
Ads 320
Oregon State University
Corvallis, OR 97331

PUERTO RICO

Sea Grant Program
Department of Marine Sciences
University of Puerto Rico
Mayaguez, PR 00708

RHODE ISLAND

URI Sea Grant College Program
University of Rhode Island
Narragansett, RI 02882

SOUTH CAROLINA

South Carolina Sea Grant Consortium
287 Meeting Street
Charleston, SC 29401

TEXAS

Sea Grant College Program
Texas A&M University
College Station, TX 77843

VIRGINIA

Virginia Sea Grant College Program
Madison House
170 Rugby Road
University of Virginia
Charlottesville, VA 22903

WASHINGTON

Sea Grant Program
College of Ocean and Fishery Sciences
University of Washington
Seattle, WA 98195

WISCONSIN

Sea Grant Institute
University of Wisconsin
1800 University Avenue
Madison, WI 53705

research, education, and advisory service components, and represents a partnership of government, universities, and industry. The 29 individual programs also work together, forming a network that shares expertise on regional and national levels and that responds as a cohesive unit to emerging issues. As I shall discuss later, this structure is both an opportunity and a problem.

A key Sea Grant role is to attract scientific expertise to address pressing marine and Great Lakes resource questions by providing funds for research support. Sea Grant research often focuses on fundamental questions in marine science, technology, and marine affairs, but frequently with an emphasis on the application of that science to a specific marine resource problem. Resource problems can be in areas as diverse as aquaculture, biotechnology, pollution, marine minerals, or shoreline erosion, but the

Figure 2. Four "Fathers of Sea Grant" and a former National Sea Grant College Program Director. From left to right: Robert Abel, John Knauss, Sen. Claiborne Pell, Rep. Paul Rogers, and Athelstan Spilhaus. Dr. Abel served as National Sea Grant Director from 1967–76. Dr. Ned Ostenso (see photo page 5) has been the Director since 1977.

focus often is perceived to be on a local level rather than on a national level. This perception frequently is wrong, as the various individual parts can constitute a national effort, but unfortunately there is generally little emphasis or visibility for this important point.

The second component of the National Program is marine education. Marine education covers a variety of activities, ranging from marine science curriculum development, dissemination of workshop and conference proceedings, public information communiqués, to funding graduate student support. This educational component is vital to developing a knowledgeable citizenry, which, of course, is a prerequisite to the wise use of the oceans and Great Lakes and their resources. Sea Grant, especially its larger programs, plays a leading role in marine education development in the United States.

The third component of the Sea Grant concept is its advisory and extension services. Through the efforts of marine advisory and communications personnel, current information, recent research results, and advice are provided on a local and regional level to a broad community of marine resource users, including commercial or recreational fishermen, boat owners, port and harbor managers, coastal property owners, or coastal town officials. Sea Grant marine advisory agents keep in touch with current coastal issues and organize initiatives such as workshops, project demonstrations, seminars, and information campaigns to address these issues. The output of individual programs is shared throughout the national Sea Grant community.

Networking

Sea Grant operates on a national level as a broad and effective network of individual programs. Through networking (something that has been made easier with the advent of computers and electronic mail), each individual program can access the information and expertise from all the other Sea Grant programs. The best example of this type of beneficial networking is found in Sea Grant information transfer. All Sea Grant products (books, reprints, videos, and so on) are available from the programs, and on-line computer searches can be made, covering all Sea Grant material available via the National Sea Grant Depository (at the University of Rhode Island's Pell Library). *Sea Grant Abstracts*, produced quarterly, provides a national listing of current Sea Grant publications. Sea Grant directors, educators, communicators, and advisory personnel are all a part of this network.

There are also five regional Sea Grant associations (Northeast states, Mid-Atlantic states, Southeast states, Great Lakes states, and Pacific region) and one national association. The directors of the individual programs meet within their respective regional associations, and at the national association, to discuss various problems and opportunities.

Some Financial Aspects

Twenty-two years after its inception, Sea Grant remains a model program because of the interaction between government, universities, and industry. This linkage and cooperation are ensured in the Sea Grant Act by the stipulation that a third of total program funding must come from nonfederal sources. This means that for each $2 in federal support, $1 must be contributed from a nonfederal source. In this manner, Sea Grant projects can tie into or be joint efforts with business, or local or state governments. Sea Grant can provide a mechanism to catalyze the entire process of developing new marine enterprises, from supporting fundamental research in the

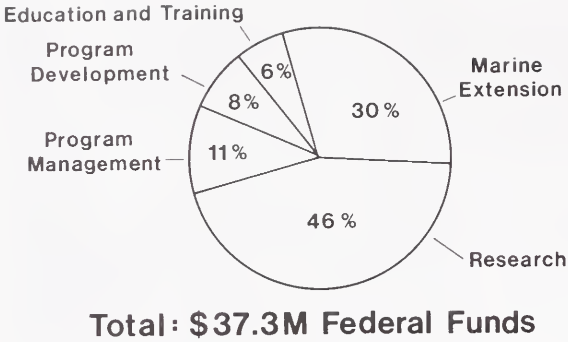


Figure 3. Sea Grant funding by program area, FY 87.

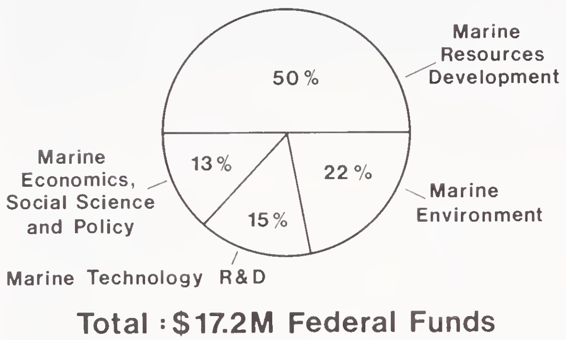


Figure 4. Sea Grant research funding by subject, FY 87.

laboratory, to implementing pilot projects in the field.

Despite the innovation and soundness of the Sea Grant concept, Sea Grant has never been a financial "fat cat." In fact, since 1981 Sea Grant has been level-funded each year at about $39 million. The budget for FY 87 was $37.3 million spent on research, marine extension, education and training, program development, and program management (Figures 3 and 4). This level-funding has not come easily, and has followed the same path each year: OMB first eliminates or zeroes out the proposed Sea Grant budget, and Congress then restores the budget. There have been interesting variations year to year, but the result has been generally the same. In the face of inflation, it has become progressively more difficult to maintain program cohesiveness and productivity from year to year with a constrained budget.

The vexing aspect is that this squeeze comes at a time when renewed affirmation of the Sea Grant concept would make obvious sense and is clearly in the nation's best interest. "Economic competitiveness" is the current shibboleth in Washington, and deservedly so. In fact, this is where Sea Grant could shine, and where Sea Grant could make its major impact. Yet the funding is not there. This is especially ironic in view of the move other countries are now making toward developing programs modelled after Sea Grant, for the same sound reasons proposed by Spilhaus in 1963.

The Future

The budget deficits of recent years are forcing our government to establish priorities concerning federal spending. This will certainly impact scientific research and the marine community. In early 1988, Frank Press, President of the U.S. National Academy of Sciences, urged the scientific community to assist the government in establishing such priorities among the various scientific fields. He proposed that the highest funding priority go to three areas: 1) training and research grants reaching the largest number of scientists, engineers, and clinical researchers; 2) responding to national crises, such as AIDS research and restoring the nation's space launch capacity; and 3) extraordinary scientific breakthroughs, such as high-temperature superconductivity.* Although Press did not say it, I submit that the quality and use of our coastal oceans are approaching a national crisis, and that the condition of this part of the ocean needs to be recognized as a national priority.

Sea Grant is in a very dynamic situation since it functions at both the national and local levels. On the national level, the Sea Grant structure, with its broad marine constituency, could develop planning and operations among multiple institutions, joining universities with government and industry. It really is, however, at the local or state level where Sea Grant mainly operates, and where its presence is so effective. To maintain the local or state constituency requires considerable cost and effort. There are expenses for the management of the institutional program, for the advisory program, and for local research projects. The latter are especially necessary since many programs receive matching funds from their states, thus requiring a focus on state marine problems. I do not mean to imply that this is an incorrect approach, but rather that this approach can result in more attention to local/state issues than to those of a more national nature. The impact and necessity of local projects has increased in recent years because of federal budget cuts to the Sea Grant Program by OMB, and the necessity of congressional action to counter them. Certainly, one of the reasons that Sea Grant has been strongly supported by Congress, and thus has survived as a program, is the value to congressional constituencies of projects that contributed to the solution of local problems. As I previously said, sometimes a collection of local Sea Grant projects can contribute to a national research program, but this point is not generally very obvious.

From a national program view, however, pressures for a local focus clearly present a dilemma. How can a sound national program be developed within a fixed (and often eroding)

* National Research Council, *News Report*, May 1988, Vol. 38, No. 5, p. 13.

budget without some local aspects being reduced? A potential answer is contained in the Sea Grant reauthorization legislation, the "National Sea Grant College Program Authorization Act of 1987," which reaffirmed the basic Sea Grant concept and the Sea Grant International Program, and added several new aspects, such as a Strategic Marine Research Program, and a Marine Affairs and Resource Management Improvement Grant.

The international program recognizes that much of the Sea Grant activity supported in the United States is transferable, and many times is essentially what foreign countries wish to learn about their own coastal environment. This part of the Sea Grant legislation unfortunately has not received financial appropriation during the last few years, but some institutions, such as the Woods Hole Oceanographic Institution and Oregon State University, are still pursuing modest international efforts.

The Strategic Marine Research Program is an excellent opportunity for Sea Grant to respond to emerging national issues and priorities. The new legislation requires that a three-year plan be developed to "1) identify and describe a limited number of priority areas for strategic research in fields associated with ocean, coastal, and Great Lakes resources, and 2) indicate the goals and timetables for the research in those fields." This Strategic Marine Research Program presents a definite challenge in that, as of the writing of this article, no specific funds have been appropriated for it. Nevertheless, it is a challenge that must be taken, and some priority areas are now being targeted. The program should not be a repackaging of present Sea Grant research, and it must focus on national needs.

One clear target area for a strategic research initiative under this program has emerged—the coastal ocean. It is an obvious choice since a major portion of the U.S. population lives within an hour's drive of the ocean or one of the Great Lakes, and because it is this coastal region that is most subject to environmental impact. Ironically, it also is this area, comprising our Exclusive Economic Zone (EEZ), that holds considerable economic potential—for fish, minerals, recreation and tourism, even for some safe forms of waste disposal. Remember, it is the challenge to both use this environment (with recreation and tourism among our largest growing industries) and protect it, that is inherent in the principles of the original Sea Grant legislation.

Two strategies are developing to meet the challenge of the Strategic Marine Research Program. The first is a broad-based approach, documented in a recent white paper on the U.S. coastal ocean, produced by Sea Grant directors. This document proposes five areas that the various Sea Grant institutions collectively have the capability to pursue:

- Sediment and shoreline stability;
- Coastal ocean mineral resources;
- Fisheries recruitment prediction;
- Impact of water quality on coastal ocean resources; and
- Marine biotechnology.

Sea Grant already has a foothold in these areas, however, and although the subjects are not a coherent package, they represent areas of critical concern for a large portion of the U.S. population.

The second approach is to pick a single issue with focused goals. One example proposes to look at a particular resource—placers or heavy mineral deposits—and to define what is necessary for an environmentally safe exploration and exploitation program of these minerals. Several offshore areas of the United States have such potential deposits (see article by Peterson and others, page 21). At present the United States is dependent on imports for several critical placer minerals that could be recovered from our EEZ. These include cobalt (86 percent presently imported), platinum metals (88 percent), and chromium (75 percent). If some of these minerals can be recovered in an environmentally safe manner from our EEZ, the need for imports would be reduced and a reliable supply would be assured.

This concentration on a single subject might be more appropriate for a strategic research initiative, but its flaw is that it should be part of a total national plan on how to use the oceans. Until a national plan is developed for ocean use and conservation, and defines the role of the federal government, academia, and industry, our realistic use and conservation of the ocean will continue to be piecemeal in approach.

In conclusion, Sea Grant is a dynamic organization with the national program coordinating individual Sea Grant programs, each of which is trying to meet local needs, earn state support, participate in national efforts, and maintain congressional support. The future that lies ahead for Sea Grant turns on whether there is a national plan for the oceans. A national ocean policy is needed that will unite the varied objectives of federal agencies, academia, and industry into a coherent and cohesive whole. Sea Grant's creation 22 years ago was considered revolutionary. Its performance and accomplishments over the years have proven that Sea Grant is an important national investment in the future of the seas.

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Acknowledgments

I would like to thank Judith Fenwick and Alan White for their reviews and comments on this article.

Estuary Rehabilitation: The Green Bay Story

by Peyton L. Smith, Robert A. Ragotzkie, Anders W. Andren, and Hallett J. Harris

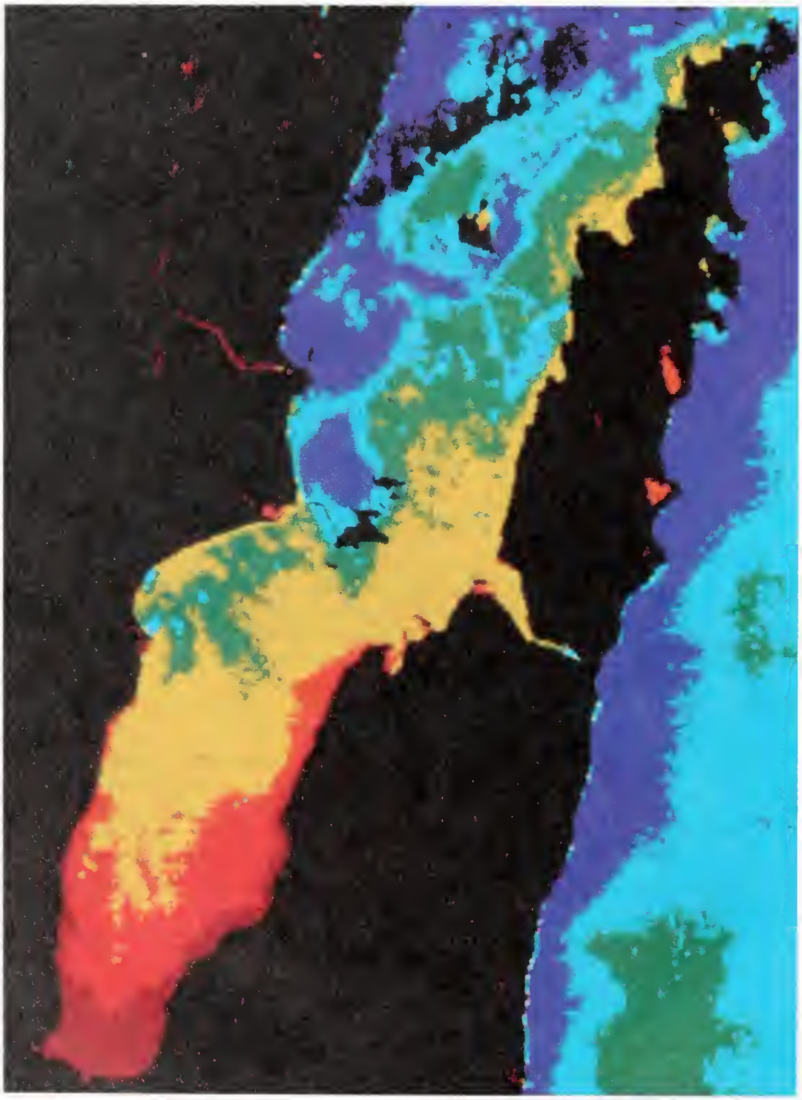

Figure 1. Landsat-5 Thematic Mapper imagery of the surface water temperature of Green Bay in July 1986 reveals the bay's large-scale circulation, the mixing of Fox River water (at lower left) in the bay, and the influx of colder water from Lake Michigan. Key: red is warm and violet is cold. (Image courtesy of Environmental Remote Sensing Center, University of Wisconsin-Madison)

The largest freshwater estuary in the world, Lake Michigan's Green Bay is located in the heart of North America. From 705 kilometers above Earth, satellite images reveal that the waters of Green Bay undergo the complex mixing processes typical of coastal estuaries (Figure 1).

Green Bay is best characterized as an estuary since it functions as a nutrient trap, has exceptionally high biological productivity, and because of the thermal and chemical differences between the water of its tributaries and that of Lake Michigan. The bay's mixing process is driven by a strong wind-induced seiche* coupled with a small lunar tide.

Green Bay is a semienclosed body of water located on the northwest side of Lake Michigan (Figure 2), one of the five Laurentian Great Lakes—"inland seas" that contain a fifth of the surface freshwater on the planet, and lie across the boundary between Canada and the United States. In size and characteristics, the Green Bay estuary resembles the Delaware Bay estuary on the Atlantic Coast.

Like all estuaries, Green Bay's abundant fish and wildlife, and its rich marshes have attracted people for thousands of years. Native Americans thrived there before French explorers and fur traders penetrated the area 350 years ago. Starting in the 1880s, commercial fishermen netted abundant stocks of fish; lumberjacks cleared the region's mature forests; and industry, cities, and agriculture grew to dominate the watershed.

The most important river in the Green Bay watershed is the Lower Fox, which runs from Lake Winnebago—a large, nutrient-rich lake—to southern Green Bay. Approximately 750,000 people live in the Green Bay watershed, more than 400,000 of whom live in the highly industrialized Lower Fox River valley. Today, 13 paper mills and five major municipal wastewater treatment facilities line the banks of the Fox River. Agriculture also is important; the rich clay loams of the watershed are well suited for both pasture and crops.

*A wave that oscillates in lakes, bays, or gulfs from a few minutes to a few hours as a result of seismic or atmospheric disturbances.

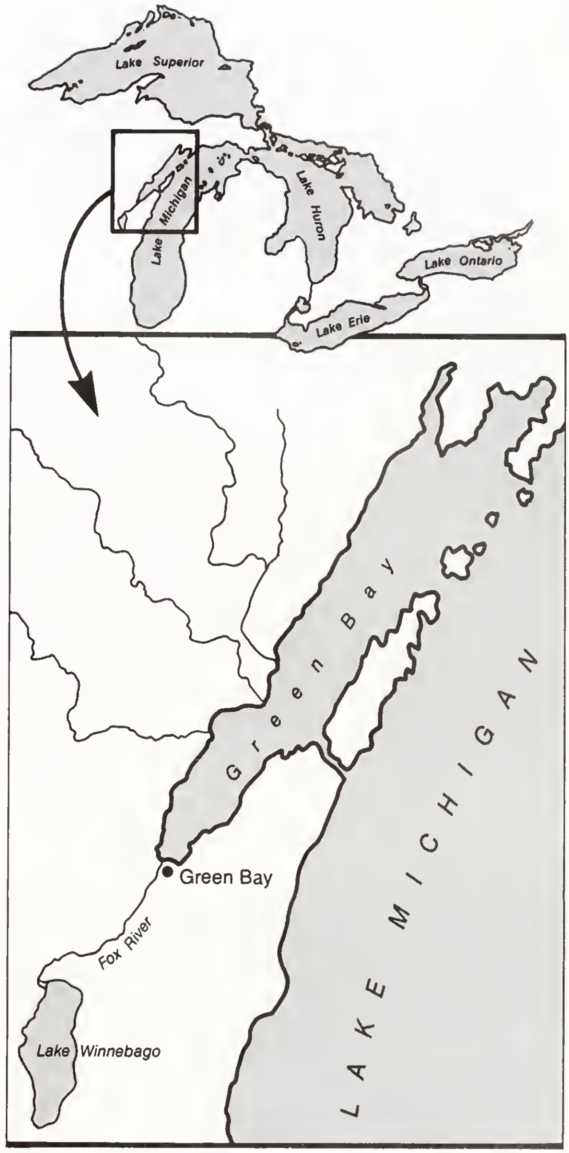

Figure 2. Green Bay is 193 kilometers long, has maximum depths of 30–35 meters, a surface area of 4,200 square kilometers, and a volume of 70 cubic kilometers. Its watershed drains an area 40,000 square kilometers. (Courtesy of University of Wisconsin Sea Grant Institute)

While Green Bay has remained tremendously productive over the years, misuse and overexploitation subsequently degraded its water quality, destroyed its fish and wildlife habitat, and imbalanced its biological systems. Green Bay became a typical heavily used estuary in an industrialized setting.

Serious problems have existed there for nearly a century, but Green Bay and its tributaries received relatively little scientific study until 1969, when the University of Wisconsin Sea Grant Program initiated a comprehensive

View of Green Bay's industrial waterfront and the Fox River, circa 1899. (Photo courtesy of State Historical Society of Wisconsin)

research program on Green Bay and its estuarine system. Much of what is now known about the system is a result of these studies, made during the last 19 years.

Largely as a result of this Sea Grant research program, the Green Bay estuary today is the focus of an international and multiagency effort to rehabilitate the ecosystem and restore

Group of commercial fishermen at Green Bay's Booth Fishery, 1909. (Photo courtesy of Neville Public Museum of Brown County, Wisconsin)

the value of its resources. The lessons being learned there offer a model for estuarine research and rehabilitation worldwide.

The Era of Exploitation

Exploitation of the Green Bay estuary offers a classic example of where economic activities focused on the land and water have led not only to enormous benefits but also to large and unanticipated consequences.

Soon after the rapid population growth and industrialization of the mid-1800s, the fish, timber, land, and water of Green Bay and its watershed faced increasing pressure. Green Bay's ability to trap nutrients hastened its degradation under the increasing loads of biological oxygen-demanding wastes and suspended solids flowing into it from the Fox River and other tributaries.

In the late 1800s, the forests of northeastern Wisconsin and the Upper Peninsula of Michigan were cut to feed lumber markets to the south, and sawmills on Green Bay's tributaries discharged sawdust that sometimes coalesced into mats covering several square kilometers of the bay. The cleared land was converted to agriculture, and runoff from farmlands had increased the nutrient load on the bay by the turn of the century. The Lower Fox River was dammed for hydropower, and the expanding concentration of paper industries and communities discharged increasing amounts of untreated sewage and industrial wastes into the river.

The harvest of the bay's whitefish, herring, sturgeon, yellow perch, walleye pike, lake trout, chubs, suckers, and catfish began to decline in the late 1800s and early 1900s because of pollution, habitat destruction, overfishing, natural competition among species, and the vagaries of the physical environment.

Organic pollutants robbed water in the Fox River and lower Green Bay of dissolved oxygen. Midsummer fish kills were common in the Fox River during the 1920s, and in the late 1930s severe oxygen depletion, caused by paper mill discharges of oxygen-demanding sulfite liquors (chemical residues of pulping operations), extended 30 kilometers up the bay from the mouth of the Fox River. The fisheries and the entire ecosystem were destabilized by the introduction of exotic species, which began in the late 1800s and continues today: carp, smelt, sea lamprey, alewives, pink salmon, and even exotic phytoplankton and zooplankton severely perturbed the bay's ecosystem. Several of the bay's most valuable fisheries—such as lake sturgeon, herring, and lake trout—collapsed. The southern bay's yellow perch catch plummeted from 2.4 million pounds (1,089 metric tons) in 1943 to only 162,000 pounds (73 metric tons) in 1966.

The degradation of water quality also affected human use of the resource. After repeated summer closings, Green Bay's public beach was permanently closed in 1943 because of high levels of fecal coliform bacteria. In 1955, the city built a pipeline some 50 kilometers long to obtain adequate supplies of drinking water from Lake Michigan, since the groundwater table was dropping, and pollution concerns prevented the city from tapping the nearby river and bay for domestic use.

For the most part, the problems continued unabated until the late 1960s and early 1970s. In the early 1970s, polychlorinated biphenyls (PCBs) were discovered in the water, sediments, and fish of the Fox River and Green Bay. Since PCBs bioaccumulate in the food chain, they are most concentrated in predator fish, thus posing a health risk to humans, birds, and other animals.

Since the 1800s, whitefish have been a mainstay for commerical fishermen in the Green Bay, providing a staple for cookouts, regional specialties, and traditional fish fries. (Photo by Rick Evans)

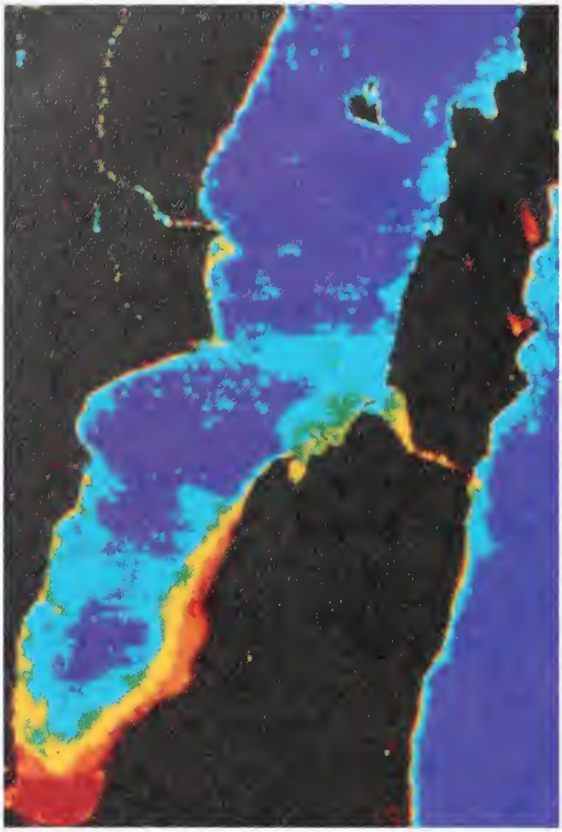

Figure 3. Landsat-5 Thematic Mapper imagery of the secchi disk depth reveals the influx of sediments into the lower bay from the Fox River and the steep gradient up the eastern shore due to suspended sediment, phytoplankton, and the general water circulation. Key: red represents a secchi disk depth of less than 0.6 meters, violet represents a secchi disk depth greater than 4.0 meters. (Image courtesy of Environmental Remote Sensing Center, University of Wisconsin-Madison.)

Understanding How Green Bay Works

Early investigations of the University of Wisconsin Sea Grant Program on the physics, chemistry, trophic structure, and geology of the bay revealed an extremely diverse system about which surprisingly little was known.

During most of the year, the waters of the Fox River and several smaller rivers that empty into the west side of the bay are warmer than Lake Michigan, and therefore tend to remain on the surface (Figure 1). Cooler water from Lake Michigan enters at depth through several channels at the north end of the bay. This two-layered system operates somewhat like a conveyor belt, with the warmer, nutrient-laden surface water moving northward, and the cooler Lake Michigan water moving southward at depth.

Much like a saltwater estuary, vertical mixing is driven by a tide-like oscillation called a seiche. Seiches are wind-induced free oscillations of the water, rather like the sloshing of water back and forth in a bathtub. This type of motion is a dominant feature of the Great Lakes. The Green Bay seiche is especially strong due to the coincidence of the period of the bay's free oscillation with the periods of the free oscillation of Lake Michigan and the semidiurnal lunar tide. The vertical range of this oscillation at the southern end of Green Bay (at the city of Green Bay) is usually only 20 to 30 centimeters, but under strong northeast winds the water level can fluctuate a meter or more.

There also is a tendency for a horizontal counterclockwise gyre to develop, resulting in a northward flow along the east shore and a southerly drift along the west shore of the bay. This large-scale circulation, coupled with seiche-driven mixing, leads to rapid mixing of Fox River water with the bay as a whole, and ultimately with Lake Michigan proper. Based on dilution rates throughout the bay, the average residence time of Fox River water, and hence of any dissolved pollutant in the lower half of the bay, ranges from 100 to 160 days, depending on the rate of flow of the river.

Suspended particles also play an important role in the Green Bay system. The Fox River, which is a major determinant of water quality in Green Bay, delivers about 70 percent of the nutrients, suspended sediments, and organic contaminants that enter the bay. During periods of high flow, plumes of sediment-laden water can extend 20 kilometers or more from the mouth of the Fox River up the east shore of Green Bay. Much of this sediment initially settles out in the shallow southern end of the bay, where it is repeatedly resuspended by wind action and eventually transported northward by wind-driven currents (Figure 3). The ultimate sediment sink is not Lake Michigan, however, but the lower half and mid-section of the bay (Figure 4).

The movements, repeated resuspension, and ultimate sedimentation of these particles are critically important to the nutrition of the bay, and to the transport and ultimate disposal of toxic contaminants. PCBs, which are major contaminants in the Green Bay-Fox River system, are a case in point. Recent Sea Grant studies to determine the sources, transport, and fate of PCBs in the Fox River-Green Bay ecosystem provide a model that scientists believe is typical for many estuaries, and many other toxic compounds.

Although PCB use in the United States has been banned since 1976, these ubiquitous compounds were, and continue to be, discharged into the river in pure form, dissolved in solvents, or attached to particulate matter. Heavy metals, and man-made chemical compounds, such as PCBs, polychlorinated dibenzo-p-dioxins (dioxins) and polychlorinated dibenzofurans (furans), are extremely insoluble in water, which means they tend to associate with phytoplankton, suspended solids, or bottom sediments—as opposed to remaining in a "pure" dissolved state in water.

Everett Marks (right) and his brother Eugene head out to the bay to set their perch nets. (Photo by Rick Evans)

Figure 4. Mass sedimentation rates throughout Green Bay were determined by lead-210 dating cores from more than 30 stations. Deposition is restricted to water depths in excess of 9 meters. Rates in the central bay "hot spot" exceed 200 milligrams per square centimeter per year. These rates are higher than in the deepest area of the bay just to the north, where rates only reach about 50 milligrams per square centimeter per year). (Courtesy of University of Wisconsin Sea Grant Institute)

The degree and strength with which a contaminant attaches to a particle depends both on the contaminant's physico-chemical properties and on the type of particle involved. PCBs, for example, are easily attracted to organic-rich particulate matter. Once PCBs enter the river, most of the compounds are adsorbed on particles and settle out in the bottom sediments, especially during periods of low flow.

During periods of heavy runoff, usually in the fall and late spring, river sediments and associated PCBs may be flushed into the bay. Most annual water and sediment transport occurs during these intense runoff periods, and it is likely that a major part of the annual PCB river transport occurs at these times. Once PCBs reach the bay, their concentration in the water column drops dramatically, because of settling and dilution.

While most Fox River water and associated dissolved chemicals can be expected to eventually flow out of the bay, PCBs remain in the bay for a much longer time. A PCB-associated particle may be resuspended hundreds of times before it settles out and is permanently buried in the bay's depositional zones. So sediments continually recycle PCBs back into the water column and food chain.

This is presently the case in the Fox River, where severely contaminated sediments, some of which contain PCB concentrations as high as 70 parts per million (milligrams per kilogram), contribute most of the PCBs that the river annually delivers to the bay. Industrial PCB discharges into the Fox River are believed to be around 10 to 20 kilograms per year, yet current estimates indicate that amounts on the order of 500 kilograms of PCBs are annually transported into Green Bay by the Fox River. Depending on the type of PCB, 60 to 75 percent of the total load appears to be associated with suspended particles. Even if all PCB inputs to the Fox River and Green Bay stopped, several decades would pass before half of the PCBs now in the system would be permanently buried or removed. This contrasts sharply with the water residence time of 100 to 160 days in the lower bay.

Since PCBs are also adsorbed efficiently on phytoplankton, the fate of PCBs is also strongly tied to the behavior of phytoplankton, which provide a direct route into the food chain. PCBs become progressively concentrated as they move up the food chain from phytoplankton to zooplankton, forage fish, and predator fish. As a result, many of the bay's large fish, such as lake trout, walleye, and chinook salmon have been found to bioaccumulate PCB concentrations 100,000 to one million times greater than the concentrations in surrounding waters.

Green Bay also is characterized by a strong south-to-north trophic gradient. The average carbon fixation rate ranges from 80 milligrams of carbon fixed per cubic meter per hour in the extremely productive, or "hypereutrophic," southern end of the bay, to 10 milligrams per cubic meter per hour in the less productive, or "oligotrophic," northern end of the bay. Continued inputs and sediment recycling of nutrients and/or chlorinated hydrocarbons, such as PCBs, appear to disrupt species composition and size distribution of phytoplankton as well as the size distribution, grazing rates, and consumptive capacity of zooplankton. This disruption appears to reduce food chain efficiency in southern Green Bay. In the mid-bay region, with its higher trophic transfer efficiencies, this nutrient influx appears to act as a subsidy. In the oligotrophic northern region, the nutrient perturbation has little effect.

Stresses of both nutrients and toxics may divert primary productivity from the grazing food chain and thus favor detrital organisms such as bacteria, worms, and carp. In addition, the overabundance of large blue-green algae, other phytoplankters, and resuspended sediments cut light penetration, reducing the ratio of macrophytes to phytoplankton, and consequently affecting the littoral environment.

Wisconsin Sea Grant studies on the role of sediments as sinks for carbon, nitrogen, and phosphorus—three of the main nutrients that enter the bay—indicate that at present about 30 percent of carbon in Green Bay's sediments is recycled, while 70 percent remains buried; about 40 percent of nitrogen is recycled, while 60 percent remains buried; and about 25 percent of phosphorus is recycled, and 75 percent is buried.

Understanding the fate of these nutrients in Green Bay will help resource managers determine the bay's response time to changes in loadings. Hypereutrophic conditions still persist in the lower bay, and occasional low dissolved oxygen levels (less than 5 parts per million) still occur at the mouth of the river.

The Era of Resolution

As a scientific information base was built up, the immense productivity of the system on the one hand, and the degree of degradation on the other, became apparent. Coming as it did during the environmental awakening of the late 1960s and early 1970s, Wisconsin Sea Grant's Green Bay program soon attracted the attention of the local community, and state and federal management agencies. Out of this early research, and spurred by a public recognition of the potential value of the bay, an ambitious rehabilitation program emerged.

Since 1970, with the advent of more stringent federal and state water pollution regulations, $338 million has been invested in wastewater treatment facilities by both municipalities and industries along the Lower Fox River. The effect of this massive cleanup effort has been dramatic. Biological oxygen-demanding wastes and suspended solids have decreased by more than 90 percent, and the once nearly sterile river and lower bay have been revitalized (Figure 5). Mean summer concentrations of phosphorus in the lower bay have also decreased, and the reduced waste loading has resulted in an improvement in the abundance and composition of the benthos in the Green Bay-Fox River ecosystem.

With the improvement in water quality and concurrent fish management actions by the Wisconsin Department of Natural Resources, the fishery has made an astounding recovery. The annual quota for the commercial yellow perch catch in Green Bay has been raised from 200,000 pounds (91 metric tons) in 1983 to 400,000 pounds (181 metric tons) in 1987 (Figure 6), and the annual sport perch catch is estimated to be more than 250,000 pounds (113 metric tons). A rapidly growing walleye fishery, initiated by a mass stocking program, also has been developed in the Lower Fox River. Research managers suspect the river is now clean enough for sea lamprey to spawn there and have permanently closed one of the locks on the river to prevent lampreys from migrating into the upper watershed. Furthermore, the levels of PCBs in Lake Michigan fish appear to be declining (Figure 7).

Sea Grant scientists have done more than assemble scientific information, however. They recognized the need for community involvement early on. About 10 years ago, these scientists joined with community leaders to form Green Bay Renaissance, a group designed to rally community support behind the bay. Two years later, the group enlarged and took on a new moniker, Future of the Bay. The improvements in the estuary—together with better knowledge of how the bay works, what its problems are and

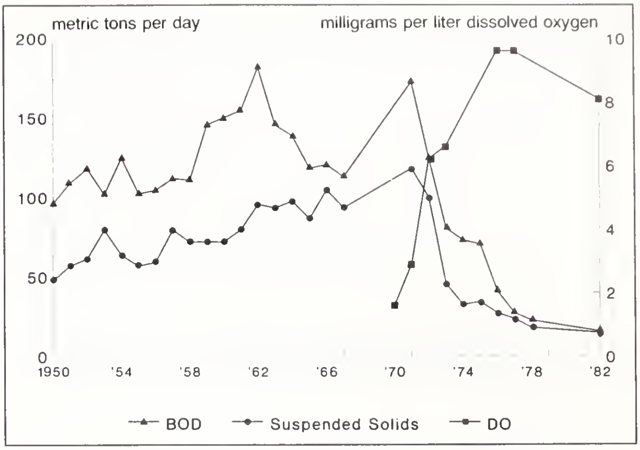

Figure 5. Average total discharge of biological oxygen demanding material and suspended sediments, Lower Fox River (after Ball, et al., 1985), and summer dissolved oxygen concentrations averaged from eight sites across the lower bay (from Harris et al., 1987).

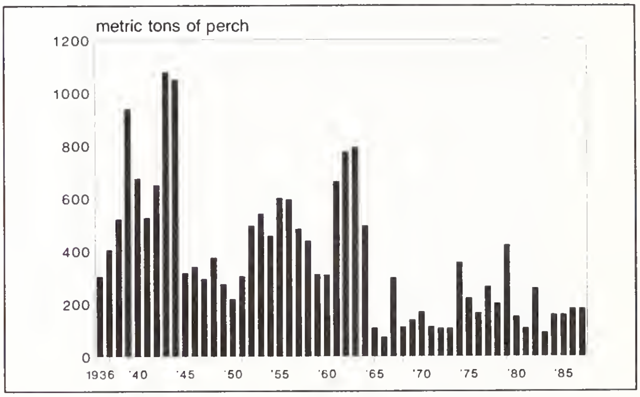

Figure 6. Southern Green Bay's commercial yellow perch harvest has fluctuated since the 1930s. In 1983, the Wisconsin Department of Natural Resources established a quota of 91 metric tons, raised to 181 metric tons in 1987. (Courtesy of University of Wisconsin Sea Grant Institute)

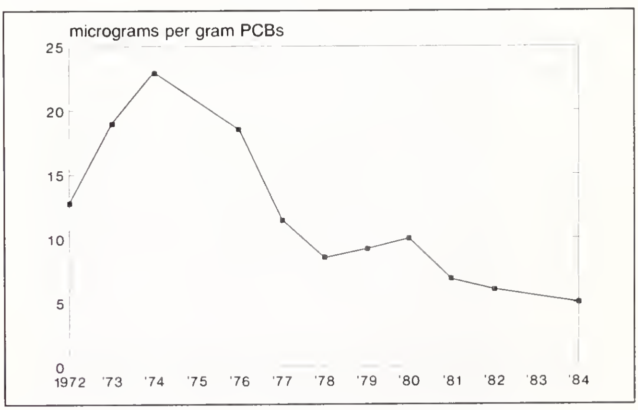

Figure 7. Mean PCB concentrations in Lake Michigan lake trout decreased during the 1970s. PCB concentrations in fish from lower Green Bay are falling, but not as quickly as those in Lake Michigan fish (from the 1987 Report on Great Lakes Water Quality to the International Joint Commission).

what its potential really is—have encouraged the community to raise its sights on what is possible. This research and community involvement ultimately coalesced into the Lower Fox River-Green Bay Remedial Action Plan (RAP).

Under a new Great Lakes-wide program of the U.S.-Canadian International Joint Commission, lower Green Bay has been targeted as one of 42 sites for Remedial Action Plans. The purpose of these plans is to restore the beneficial uses of degraded environments. With the advantages of the large information base now available, and the broad-based community and state support for rehabilitation of the area, the Green Bay RAP, under the sanction of the Wisconsin Department of Natural Resources, was completed in record time. In February 1988, it became the first such plan approved in the entire Great Lakes region.

The Green Bay RAP goals include improved water quality, reduced ecological stresses on the trophic system, restoration of safe swimming, and an edible fishery by the year 2000. The RAP has 16 "key actions" that reflect an ecosystem approach to attaining these goals. The five top priority actions are: 1) reducing phosphorus inputs from point and nonpoint sources; 2) reducing inputs of sediments and suspended solids; 3) eliminating the toxicity of point-source discharges from industry, municipalities, and other sources; 4) reducing the availability of toxic chemicals from contaminated sediments; and 5) continuing the control of oxygen-demanding waste from industrial and municipal discharges.

Until the formation of the Green Bay RAP, much of the research by Wisconsin Sea Grant investigators was diagnostic: it sought to understand the fundamental processes of the ecosystem and the problems that affected it. In the coming decade, research will be guided by the aims of this major rehabilitation project, and will focus on solutions to the serious problems that still confront the ecosystem.

Because of its importance as a microcosm of the Great Lakes, and because of the existing information base, the Green Bay area also was chosen recently as a focal point for a broad new interdisciplinary study by the U.S. Environmental Protection Agency, Wisconsin Department of Natural Resources, and Wisconsin Sea Grant—called the "Green Bay PCB Mass Balance" study. The Mass Balance Study, which has been described as a national showcase, is designed to determine the amount of PCBs that enter Green Bay from the Fox River, the degree of PCB contamination in Green Bay, the residence time of PCBs in the bay, the exchange of PCBs between the bay and the atmosphere, and the quantity of PCBs that move from Green Bay into Lake Michigan. This research also will help determine if in-place pollutants in the sediments should be dredged and disposed of, allowed to become permanently buried, or handled in some other manner. In addition, the research will determine if reduced inputs of PCBs result in reduced concentrations of these contaminants in the bay's fish. New mathematical models also could result in rapid and more economical ways to complement field and laboratory measurements.

The ongoing Green Bay story illustrates that a scientific database is only one of the essential ingredients needed to restore estuarine systems—it also takes the coming together of people from the community, industry, and government agencies. This broad-based coalescence of the community, rarely seen in scientific studies, is the key to resolving the conflicts that arise from competing uses of valuable, but perishable, coastal resources. With this new public vision of what Green Bay can be, and a continued commitment to a sound and vigorous rehabilitation program, the future for the Green Bay estuary looks bright.

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Critical Metals, and Gold, May Lie in Them Thar Waters:

Marine Placer Studies in the Pacific Northwest

by Curt D. Peterson, LaVerne D. Kulm, Paul D. Komar, and Margaret S. Mumford

After a respite of more than half a century, the mining of valuable metals in marine sands of the Pacific Northwest is once again of national and commercial interest. The marine sands that are most sought-after are called placer sands, and they are characterized by above-average concentrations of heavy minerals and precious metals. However, the placer deposits, or placers, of interest have shifted from coastal sands, originally mined for gold in the mid-1800s, to offshore sands of the continental shelf. Marine placers enriched in the heavy minerals ilmenite, chromite, and zircon occur in coastal and shelf deposits of the geologically active Cascadia margin, extending from roughly 40 to 50 degrees North latitude (Figure 1). The economic and strategic metals titanium, chromium, and zirconium are incorporated into these inert heavy minerals (Table 1), which by virtue of their high densities and small grain sizes become concentrated in the sands of the nearshore region. Such sands were most likely laid down over the continental shelf during periods of lowered sea levels.

Industries in the United States have become increasingly dependent on foreign sources for ores and feed stocks of these critical metals. Chromium and zirconium are required in the manufacture of chemically resistant alloys, and titanium has widespread use in high strength-to-weight alloys, and in nontoxic pigments. Diminishing reserves of titanium- and zirconium-bearing minerals in Australian coastal placers, and in ancient beach placers of the southeast United States have stimulated interest in the exploration of the United States continental shelf for domestic supplies of these metals.

Modern black-sand deposit at Agate beach, near Newport, Oregon. Black sands reach 2 to 3 meters in thickness, and extend several kilometers along shore during winter periods of maximum beach face erosion. (Photo by Curt Peterson)

At right, wax-impregnated core of black sands from a modern beach placer. Black grains primarily consist of the economic minerals ilmenite, magnetite, and chromite. Clear grains are comprised of garnet and zircon, also economic. Iron-rich garnets lend a pink tint to these black sands. (Photo by Curt Peterson)

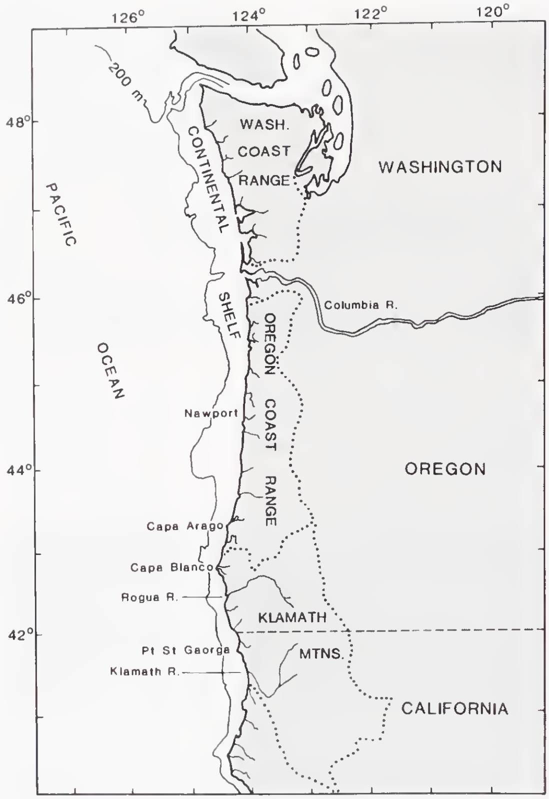

Figure 1. The Pacific Northwest, showing coastal source terrains for marine placers, selected geographic reference points, and the continental shelf (to 200-meter water depth) offshore northern California, Oregon, and Washington. The Cascadia continental margin roughly extends from Vancouver Island, British Columbia (50 degrees North) to Cape Mendocino, California (40 degrees North). (All figures by Peterson, Kulm, Komar, and Mumford)

The primary source of chromium and ferrochrome to the United States is the Republic of South Africa, a country of uncertain political stability. The 1988 domestic consumption of chromium ore in the United States is expected to be about 400,000 tons, of which about 60 percent will be supplied from the Republic of South Africa. Sea Grant studies at Oregon State University indicate a high potential for the occurrence of these critical metals in heavy-mineral placers of the Pacific Northwest continental shelf.

Geologic Setting

The origins and types of rocks ultimately determine the minerals that will be present. The Cascadia margin of the northwestern United States, because it includes a variety of rock types, has a geology that could contribute to the potential development of a variety of marine placers. Emplacements of oceanic crusts into the continental margin between 160 and 40 million years ago produced north-south linear terrains that comprise much of the coastal drainages. These accreted terrains are rich in mafic (iron-rich) rocks that are the primary sources of the economic heavy minerals. Basalts, formed in the upper part of the oceanic crust, predominate in the Washington and northwest Oregon Coast Ranges, and are the sources of the titanium-bearing mineral, ilmenite.

Ultramafic rocks, which are formed in the lower part of the oceanic crust, are the sources of chromite. The ultramafic rocks generally are restricted to the Klamath Mountains of northwest California and southwest Oregon. Igneous intrusion and hydrothermal alteration associated with the Klamath Mountain terrain has locally added gold and platinum to the host of valuable minerals in the southern coastal drainages. The sources of garnet and zircon are less well defined, but are apparently associated with igneous and metamorphic rocks of the Klamath Mountains, and possibly with recycled marine sands in thrust belts of the Olympic Mountains in northwest Washington.

Tectonic uplift of the coast ranges along the convergent Cascadia margin has resulted in rapid erosion of the mafic and ultramafic source rocks. High-gradient rivers supply the adjacent coastal areas with abundant sands containing the economic heavy minerals. The Klamath Mountain area had an exciting history of placer mining, which was initiated by the discovery of gold in numerous coastal placers during the mid 1800s. Presumably, the coastal rivers carried their economic minerals and metals out across the continental shelf during glacial periods of globally lowered sea levels. The maximum development of polar ice caps during the last glacial period (16,000 years ago) is known to have lowered the sea level by some 130 meters, causing the shoreline to traverse most of the continental shelf.

The topography of the continental shelf also contributes to placer formation. Along the Cascadia margin, an irregular shelf platform, with numerous benches and promontories, has been produced by long-term tectonic deformation and differential wave erosion of rock formations during episodes of sea-level rise. These topographic irregularities must have redirected nearshore currents, much as the bends in a river that alter the downstream flow, or the sides of a gold pan that slosh the water from side to side. In either case, it is the localized drop in current velocity that permits the heavy minerals and precious metals to fall out as a placer lag. Various shelf irregularities likely served as placer traps when they were intersected by the changing shoreline positions on the continental shelf.

Placer Mineral Enrichment

Beaches provide a glimpse of the nature of the huge offshore reservoir of placer sands. On the Northwest beaches, placer formation is an active process, and at places, high concentrations of the opaque minerals (ilmenite, magnetite, and chromite) produce black sand beaches. The total assemblage of opaque and nonopaque heavy

Table 1. Heavy minerals and metals in marine placers of the Pacific Northwest.

Native Metals		Density	Economic Value
Gold (Au)		17–19 (+ silver)	precious metal
Platinum (Pt)		14–19 (+ iron)	precious metal
Economic Heavy Minerals	**Formula**		
Magnetite	Fe_3O_4	5.0–5.2	iron, vanadium
Ilmenite	$(Fe,Ti)O_3$	4.7–4.8	titanium
Chromite	$(Fe,Mg)(Cr,Al)_2O_4$	3.8–5.2	chromium
Zircon	$ZrSiO_4$	4.6–4.7	zirconium, hafnium
Garnet	$(Fe,Mg,Ca,Al)_5(SiO_4)_3$	3.6–4.3	abrasive

(Table courtesy of Peterson, Kulm, Komar, and Mumford)

minerals are distinguished from light minerals (quartz and feldspar) by their mineral densities of greater than 2.9 grams per cubic centimeter.

The authors have documented the process of heavy-mineral enrichment on the beach at Otter Rock, near Newport, Oregon. The highest degree of mineral concentration in the placer was achieved by the titanium-rich ilmenite (density: 4.7 grams per cubic centimeter) during early winter months, when the swash of storm waves was cutting back the beach face, and concentrating black sands at the base of the sea cliff. Since the light mineral sands are carried by wave action more readily than the heavy mineral sands are, the strong waves of winter cause the separation of the sands.

For the several minerals found in Oregon beach sands, the higher the density of the mineral, the greater its concentration in the placer sands. However, this gradient also reflects decreasing grain size. Ilmenite grains are the most difficult to entrain and transport because of their higher density and smaller size range, and they tend to be sheltered behind the larger grains. This sheltering makes it more difficult for the ilmenite grains to pivot out of position over the underlying grains. Calculation of the water-flow stresses required to move the grains yielded the highest value for ilmenite, and the smallest for quartz. This confirms that the wave swash could readily transport the quartz, whereas the ilmenite would tend to remain behind as a lag (Figure 2). This same process is responsible for the sorting of fine grains of very dense gold from larger grains of sand and pebbles in a sluice box or gold pan.

Along with the sorting of minerals perpendicular to the shoreline, there are also patterns of longshore sorting of minerals within the Northwest beaches. On most Oregon shorelines, this has led to the development of black-sand deposits on the south sides of prominent headlands. This has been attributed to the asymmetry of wave energies reaching this coastline from different offshore directions. The major storm waves of winter approach the shore from the southwest, and deposit the beach sands and their heavy minerals to the south sides of headlands. Smaller waves, associated with fair-weather conditions, arrive from the northwest and move the sand back toward the south, but preferentially transport only the lighter quartz and feldspar, leaving behind a concentration of heavy minerals. In addition, the fair-weather waves effectively transport the light minerals back onto the beach face, covering the black-sand deposits under several meters of barren sand. As a result, one can usually find only black-sand deposits south of prominent headlands during winter months of beach face erosion.

One exception to the headland formation of placers is the extensive black-sand deposit on the beaches near the mouth of the Columbia River, in southwest Washington. This several-kilometer-long deposit of black sand is also the product of mineral sorting during longshore transport. The lighter minerals preferentially move alongshore away from this major river source, leaving behind the heavy minerals. Like the headland placers, this downdrift rivermouth placer is best exposed during winter conditions of severe beach-face erosion.

Modern and Ancient Coastal Placers

Reconnaissance studies of the 1,000-kilometer-long coast of the Pacific Northwest have

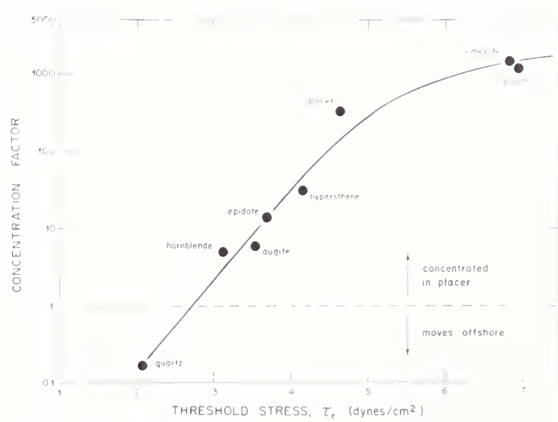

Figure 2. Threshold entrainment stress and mineral concentration factor for heavy and light minerals found on Oregon beaches. Small, dense placer minerals such as ilmenite and zircon require great shear stresses (stronger currents) to initiate transport, so they become concentrated in the backshore of beaches where currents are too weak to dislodge them.

Cape Arago, Oregon, just north of terrace placers shown in Figure 3. In the background are uplifted marine terraces, and in the foreground, a modern drift-log accumulation over a buried black-sand deposit at Sacci beach. (Photo by Curt Peterson)

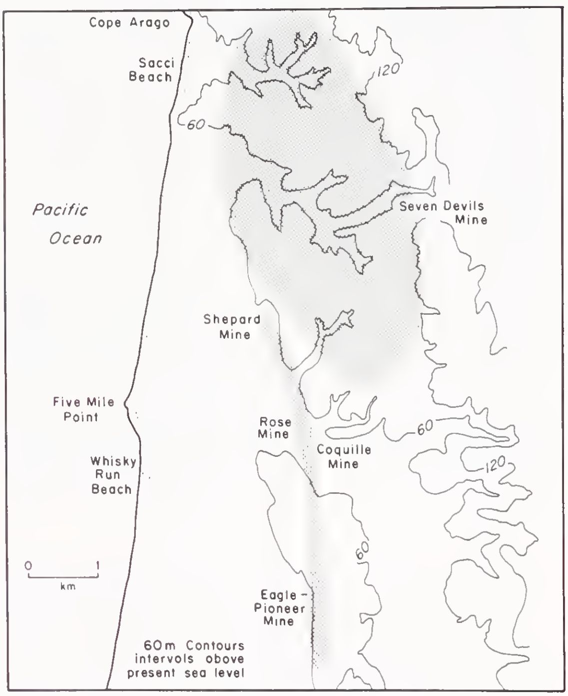

Figure 3. Ancient marine placers south of Cape Arago, Oregon. The Seven Devils and Pioneer placers are formed on adjacent uplifted terraces that were initially formed at least 100,000 years ago. The lower Pioneer placer has been extensively explored and mined for gold.

identified about 10 major placer accumulations that might reflect the potential for offshore placer development. Some of the placer locations were found by spot-checking sites that showed anomalous accumulations of drift logs in aerial photographs. Such accumulations are often associated with the slowing of longshore currents that produce some coastal placers. Once identified in the field, the larger placer accumulations were selectively trenched and mapped on aerial photographs for measurements of deposit dimensions.

Conservative estimates of these modern placers range from 0.1 to 5 million metric tons of placer sand, defined by having a heavy mineral concentration of at least 50 percent. While the modern placers are relatively small, they are very concentrated, reaching heavy mineral concentrations of greater than 90 percent with increasing depth (at least 2 meters) in the placer. High concentrations of the mafic minerals in the placers produce positive magnetic anomalies (exceeding 100 gammas* – considered a large anomaly). Across-shore magnetic profiles were obtained from one placer deposit using a portable magnetometer to outline beach placer dimensions that were buried by summer accumulations of light mineral sand.

Prominent shoreline features also have been important in controlling placer development on the Oregon coast in the geologic past. Two Pleistocene placer deposits, at least 100,000 years in age, are partially preserved on uplifted marine terraces south of a major headland, Cape Arago, in southwest Oregon (Figure 3). The terrace placers have been mined for gold, platinum, and chromite. These ancient deposits are estimated to have had at least 11 million tons of placer sand prior to the extensive surface erosion that has reduced their volume. Chromite abundances range from 6 to 13 percent in placers containing greater than 50 percent heavy minerals, as determined from ore assays conducted during mining operations in 1943. A magnetic survey of these terrace placers, performed in 1942 by the U.S. Bureau of Mines, shows that they have sufficient magnetic material to be identified by positive magnetic anomalies, which range up to 85 gammas. While the remaining terrace ore bodies are not considered to be of major commercial interest, they do provide vertical sections of the ancient marine placers that can be used to predict offshore placer stratigraphies. For example, cross-sections of the terrace deposits indicate that the richest placer sands (1 to 8 meters thick) are buried under a relatively thin cover of marine sediments.

Offshore Heavy Mineral Accumulations

The onshore placer studies contribute to the mapping and description of the potentially larger offshore placer deposits on the continental shelf. There also are a number of direct studies. For example, a federal study, *Heavy Metals Program of the U.S. Geologic Survey*, was initiated in the late 1960s to investigate the potential placer deposits of the continental shelf off the Pacific Northwest. Federal and university studies documented anomalous heavy mineral concentrations within the surface deposits of the shelf.

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*A unit of magnetic intensity, equal to 10^{-5} oersted. One oersted is the magnetic intensity one centimeter from a unit magnetic pole.

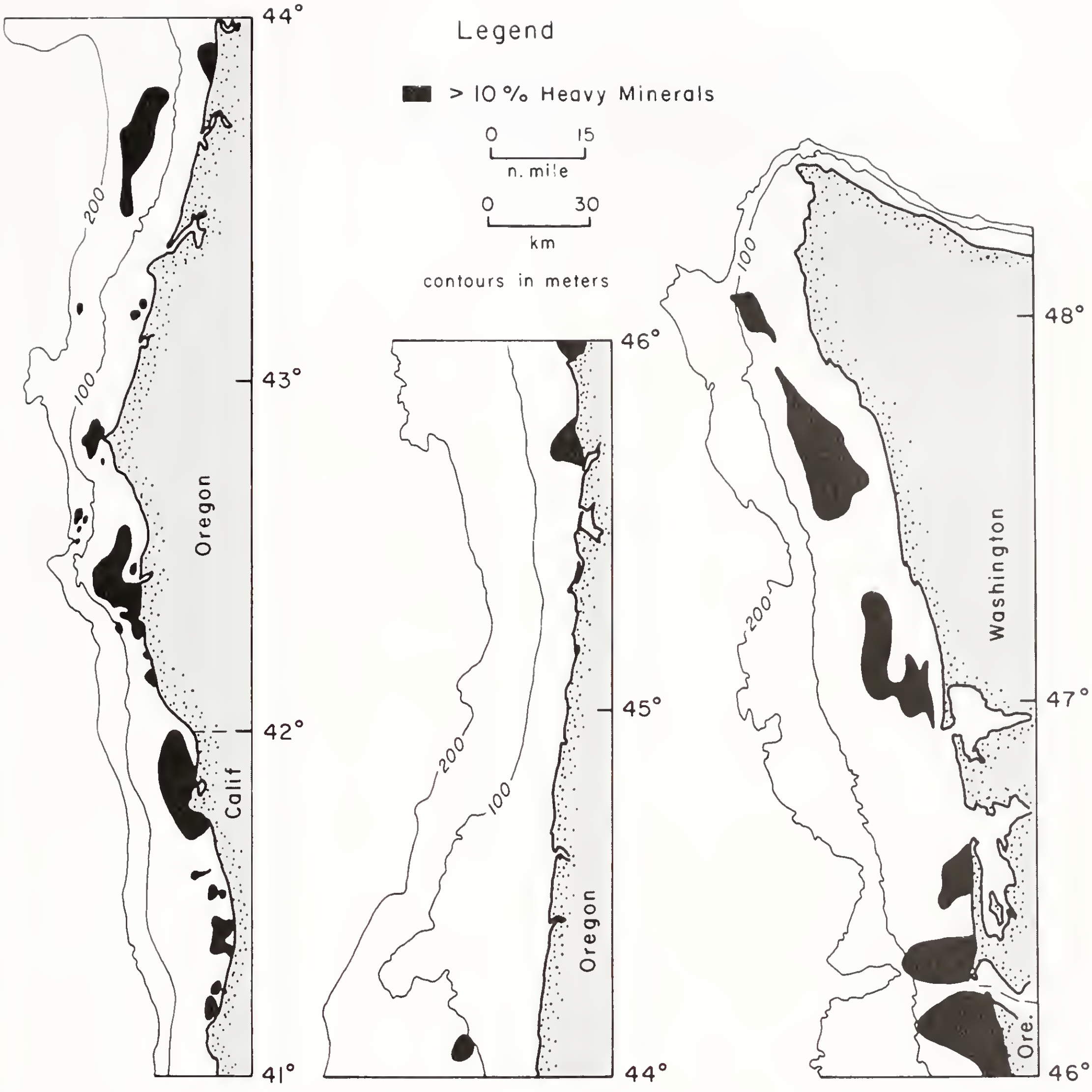

Figure 4. Heavy mineral anomaly map of continental shelf off Washington, Oregon, and northern California. Black patterns indicate heavy mineral concentrations greater than 10 percent of the sand fraction in surface sediments. Economic placer sands might underlie these elevated surface concentrations of heavy minerals.

Heavy mineral concentrations were determined by their separation from light minerals in heavy liquids, with densities ranging from 2.8 to 3.1 grams per cubic centimeter. Significant concentrations of heavy minerals (5 to 42 percent) are present in limited areas of the inner shelf off northern California (Figure 4). More widely distributed patterns of heavy mineral concentrations (10 to 56 percent) were discovered off southern Oregon. These concentration patterns occur across the inner and outer shelf. They are frequently aligned parallel to the present shoreline, indicating possible buried ancient beaches. Each covers between 10 and 200 square kilometers off Oregon, and many exceed the largest surface area of any placer deposit yet observed in the modern beaches, or in the ancient coastal terraces in the area. Insufficient sample analyses from the north-central Oregon shelf (44 to 46 degrees North latitude) preclude mapping of heavy-mineral anomalies in this area. Farther to the north, heavy-mineral accumulations are centered around the mouth of the Columbia River and along the inner shelf off central Washington. Heavy-mineral concentrations in surface deposits of these two shelf regions generally range from 10 to 35 percent, and 4 to 27 percent, respectively.

In the late 1960s, a reconnaissance magnetometer survey was made over the heavy mineral concentrations on the southern Oregon

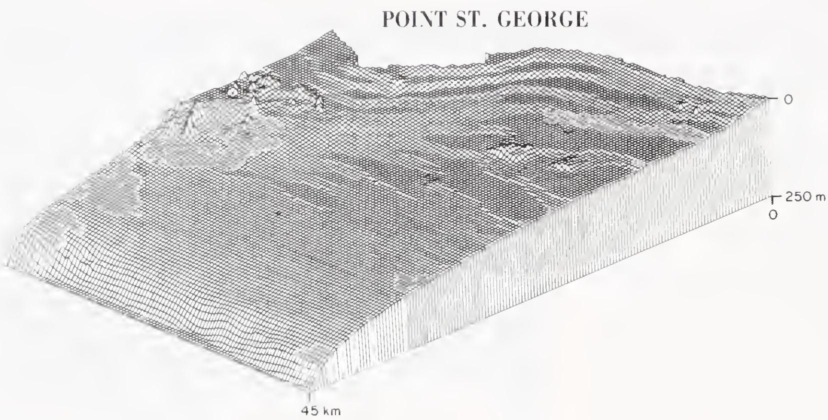

Figure 5. Computer generated three-dimensional map of shelf bathymetry off Point St. George, northern California. The fish-net pattern outlines surface irregularities of the shelf platform and overlying sediments. Promontories and benches can serve as placer traps. Prominent topographic features are generally associated with the largest heavy mineral accumulations in the shelf surface sediments.

shelf by one of the authors (Kulm). The magnetic anomalies range from 10 to 300 gammas. They have narrow, steep-sided profiles, suggesting that the magnetic source is very shallow and narrow in dimension. Depth-to-source calculations show that the tops of the two magnetite-bearing bodies are located close to the sediment-water interface, and probably lie within the upper few tens-of-meters of unconsolidated sediment overburden. The magnetic anomalies measured on the shelf are as large or larger than those anomalies measured over both the ancient terrace and modern beach placers. Assuming that the magnetic anomalies on the shelf are produced by magnetite-bearing placer bodies, the surface heavy mineral concentrations on the shelf appear to represent "halos" over large placer bodies that occur at a subsurface depth of a few meters.

One of the objectives of present studies on the shelf is to compare the observed heavy-mineral anomalies with the shelf bathymetry, and structures that define likely traps for placers. Such paleo-shoreline irregularities might have controlled shoreline currents and placer accumulation when changing sea levels crossed the shelf platform. Positive topographic features are clearly associated with the larger heavy-mineral anomalies in Oregon and northern California. Using digitized maps of shelf bathymetry, we have constructed three-dimensional block diagrams to show submerged benches and promontories that are associated with the heavy-mineral anomalies (Figure 5). Significantly, these submerged topographic features extend across inner- and mid-shelf regions, possibly controlling placer development over a wide range of sea levels. Potential placer bodies should reach maximum concentrations and thicknesses against the steepest bench slopes, and south of the east-west trending promontories.

Distribution of Potential Resources

While the broad geographic patterns of ultramafic and mafic source rocks are known in the Northwest, more precise information is needed, indicating where the economic minerals are entering the marine zone, and how they are dispersed across the continental shelf. Using instrumental neutron activation analysis, we have analyzed the highest density fractions (opaque minerals greater than 4.3 grams per cubic centimeter) of the heavy mineral sites from river, beach, and shelf-surface sands for their contents of titanium, chromium, and other elements. When the relative abundances of elemental titanium and chromium in the Northwest rivers are plotted against latitude, the geographic change in potential mineral resources is quite apparent (Figure 6). For example, titanium is the major economic resource north of latitude 43 degrees, off northern Oregon and southernmost Washington. Chromium dominates south of latitude 43 degrees (near Cape Blanco) in southern Oregon and northernmost California.

The relative abundances of titanium and chromium in the continental shelf sands generally follow the broad source-rock patterns. However, variations in the titanium and chromium content of the marine deposits vary from the expected source terrains in several important respects. First, offshore of northern Oregon, the relative abundance of titanium drops dramatically, from greater than 20 percent south of the Columbia River to less than 10 percent near the mouth of the river at latitude 46 degrees. The Columbia River, with its large intra-continental drainage, has diluted the marine placers of southwest Washington with magnetite, the least important economic placer mineral in the region. Second, elevated values of chromium and titanium overlap between latitude 42.7 degrees and 43.2 degrees in southern Oregon. Surprisingly, none of the river sources adjacent to the zone of chromium and titanium overlap appear to have sufficiently high titanium abundances to produce the observed marine concentrations (greater than 15 percent titanium). Likewise, the very high chromium values of rivers and beaches (greater than 10 percent chromium) in northernmost California are not reflected in surface sands of the adjacent continental shelf. These local variabilities in economic metal distributions indicate a very complex history of

sediment dispersal and deposition on the continental shelf.

Local concentrations of gold occur in the sandy surface deposits of the inner continental shelf off southern Oregon and northern California. The gold occurs as small particles, and it is frequently associated with the heavy mineral "halos." However, the gold content is quite low, ranging from 10 to 390 parts per billion (ppb) and from 5 to about 150 ppb, respectively, in these areas. Gold particles are present in both the modern beaches and ancient terrace placers in adjacent coastal regions, which suggests that gold also may be present in the subsurface of the continental shelf deposits. Recent work by the U.S. Bureau of Mines has shown that gold in the marine terraces of southwest Oregon can reach commercially attractive values of 2.5 parts per million (ppm), but more commonly will be of commercial interest as a co-product of heavy-mineral mining. Significantly, the gold is associated with both the basal cobbles and the overlying black sands. The apparent hydrodynamic equivalence of the gold and black sand minerals indicates that very fine gold particles can be readily transported over long distances on this high-wave-energy coast, and are not restricted to river-mouth deposits.

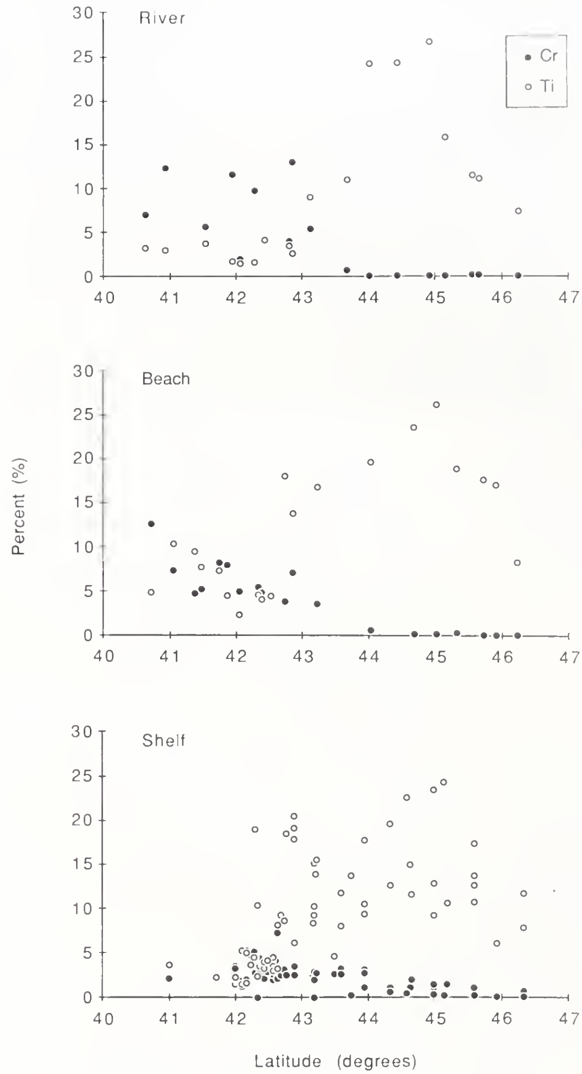

Figure 6. Titanium (Ti) and chromium (Cr) content in opaque mineral separates (mineral fractions with density greater than 4.3 grams per cubic centimeter) of rivers, beaches, and shelf-surface sands from the Pacific Northwest, south of 46 degrees latitude. The highest values for chromium occur in northernmost California and southern Oregon (south of 43 degrees latitude) while the highest values for titanium are found in central and northern Oregon (north of 43 degrees latitude).

Future Exploration and Mining

The geographic distributions of several strategic and commercially valuable metals on the Northwest continental shelf have been established. However, a broad-based research program at sea is ultimately required to test the models of shelf placer development, and to evaluate resource reserves on the shelf. Specifically, reconnaissance magnetic profiling can be used to identify potential placer bodies that might underlie heavy mineral anomalies, or be associated with prominent topographic traps on the shelf.

Once placer ore bodies are suspected, several techniques are available to confirm their maximum depth below the surface, grade of economic mineral assemblages, and overall size. For example, the most promising areas can be acoustically profiled by seismic reflection to establish the thickness of the sediment cover over the shelf platform. Target sites with minimum overburden could be selected for coring to 10 meter depth to confirm placer accumulation, and for detailed analysis of heavy mineral composition. Recent developments in precision navigation, high-resolution magnetic surveying, vibra-jet coring and rapid elemental analyses at sea will provide the necessary technologies to accurately evaluate these potential offshore resources in a timely and cost-effective manner.

Several of the heavy mineral concentration patterns that occur off the Northwest Pacific coast are located within the three-mile territorial seas of California, Oregon, and Washington, and within the federal Exclusive Economic Zone beyond the state territorial seas. Agencies of the coastal states and the federal government have complex and overlapping sets of rules and regulations for the exploration and/or mining of the hard mineral resources on the contiguous continental shelf.

In response to industry interest in the potential heavy-mineral resources on the continental shelf, the State of Oregon passed legislation in 1987 to develop a comprehensive plan that 1) provides for the commercial development of these potential mineral deposits,

Klamath River mouth in northern California. The Klamath River and other drainages in southwestern Oregon were extensively worked for gold placers in the late 1800s and early 1900s. The first record of a beach placer worked for gold (1851) was at Gold Bluff beach, located south of the Klamath River mouth. (Photo by Curt Peterson)

and 2) will assure the responsible conservation of Oregon's living ocean resources. Similar legislation is likely to be considered in the adjoining states and federal government during the next few years.

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Acknowledgments

Financial support for this research was provided largely by the Oregon State University Sea Grant Program, supported by NOAA Office of Sea Grant, U.S. Department of Commerce, under grants No. NA81AA-0-00086 Projects R/Cp-20 and R/Cp-24 and No. NA85AA-D-SG095 Project R/Cm-31.

View of the upper 1.5 meters of a 4-meter-thick black-sand deposit in a placer mine pit on the Pioneer terrace. The shovel handle is 1 meter in length. The black-sand deposit, containing fine gold, is overlain by light mineral sand from beach and wind-generated dune deposition. (Photo by Curt Peterson)

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Sea Grant Network Tangles with Castoff Plastic Debris

by Dan Guthrie

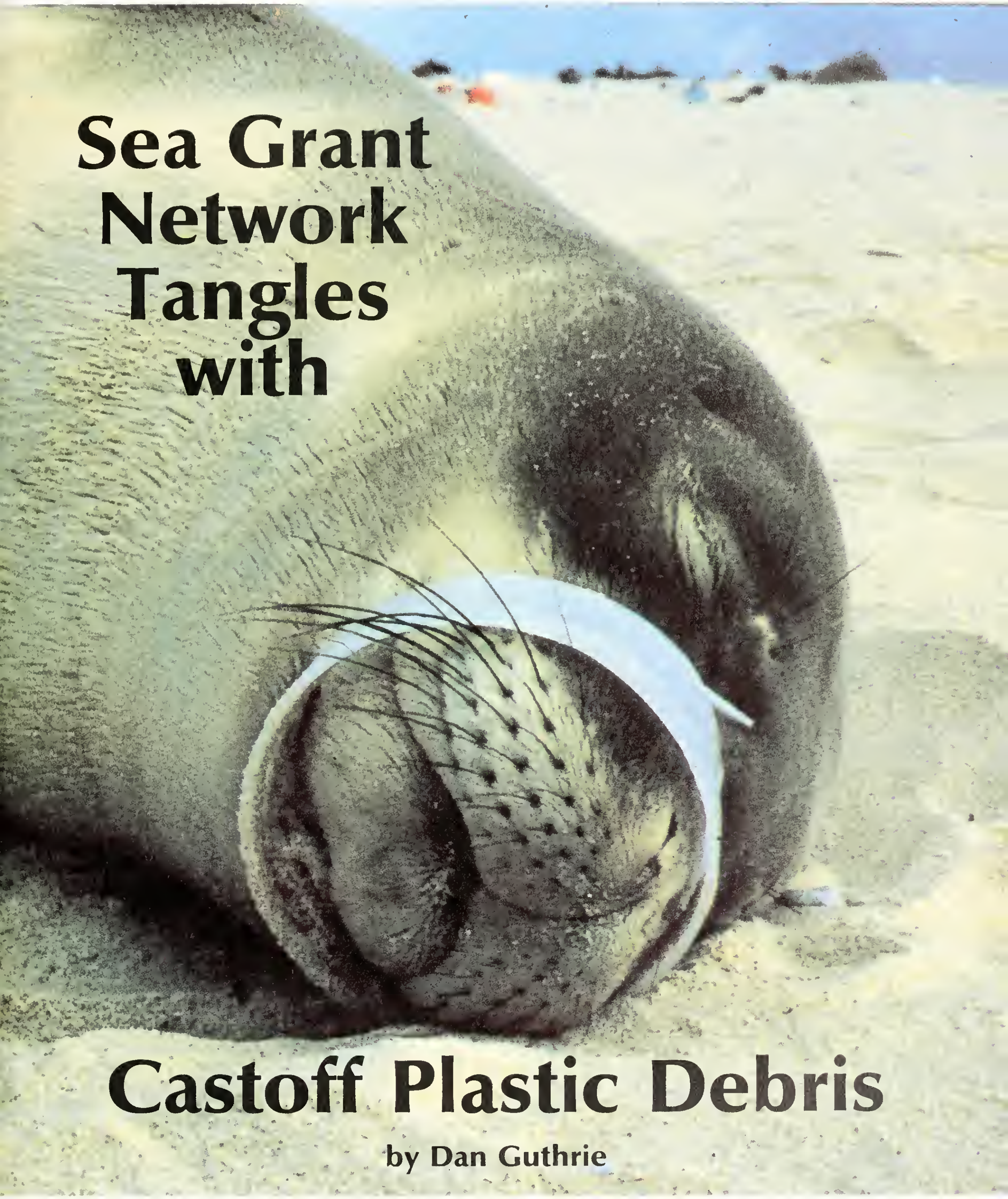

Photo courtesy of Center for Environmental Education.

There were no plastics on the planet in 1812 when Lord Byron wrote:

Roll on, thou deep and dark blue Ocean–roll!
Ten thousand fleets sweep over thee in vain;
Man marks the earth with ruin–his control
Stops with the shore; upon the watery plain
The wrecks are all thy deed, nor doth remain
A shadow of man's ravage, save his own...

Byron might revise those lines were he to see how his insignificant fleets have grown, and more importantly, changed the nature of their garbage. Ships in the 19th century disposed of rottable items such as jute, canvas, staves, and moldy biscuits, whereas today's fleets specialize in nonbiodegradables. For example, the National Academy of Sciences has estimated that commercial fishermen alone dump or lose more than 350 million pounds of nonbiodegradable material per year. The new garbage is similar to the old in one important respect, though. It gets dumped offshore. This we know since only 3 percent of the ships that dock at U.S. ports leave anything in the trash bins. What these ships discard at sea does, eventually, come ashore. Every day, more than 30 tons of garbage wash onto Texas beaches alone. Unbreakable bottles, chunks of Styrofoam, tampon applicators, plastic bags, nylon fishing nets, styrene packing pellets: they mount along tide lines once demarcated by seaweeds and shells.

The upshot is that plastics have fouled our oceans. The consequences are bad for both economies and wildlife. Coastal states spend millions annually to pick up beach litter that threatens to blight a multi-billion-dollar tourism industry. Commercial fishermen log downtime because of encounters with debris. Trash can also be lethal. For example, seabirds often mistake resin pellets for fish eggs, and ingest the undigestible material that can eventually kill them. Birds, fish, and marine mammals frequently fall victim to entanglement in lost or discarded fishing nets and plastics, such as mesh vegetable bags and six-pack holders. The Texas Center for Environmental Education reported that in March of 1988, a stranded minke whale was found to have sheets of plastic in three of her four stomachs. Like many other 20th-century innovations—synthetic pesticides, automobiles, antibiotics, and nuclear energy—what began as a boon has become a bane. Or, as plastics industry representatives have observed, all modern revolutions involve tradeoffs.

Commercial fisherman Herb Goblirsch drew the logo for the Port of Newport refuse disposal project. His miserably yoked fish soon sprouted on hats and shirts all along the Oregon coast.

Sea Grant's Advisory Service

Solving the plastics problem will require new technologies that perfect biodegradable plastics and invent acceptable alternatives. It will require legislation that further restricts ocean dumping. But most of all, it will require educational programs that influence children and legislators, as well as those responsible for pollution. Here is where Sea Grant's Advisory Service has been active.

Patterned after the Extension Service of Land Grant universities, the Advisory Service comprises a network of marine agents and specialists in the coastal and Great Lakes states. They are housed at Sea Grant universities and work closely with many maritime activities, such as commercial and recreational fisheries, seafood marketing, port authorities, aquaculture projects, tourism, and coastal development. As educators whose backgrounds are in marine natural resources, they often find themselves at the center of controversies over those resources. They must be environmentalists and public educators, as well as advisors to industry.

The Sea Grant Advisory Service took shape late in the 1960s. At that time, barnacle-encrusted bottles were still rare enough along much of the nation's coastline to make suitable mantelpieces, and a Singapore bleach container would have been greeted with curiosity rather than curses. But within a decade, the dangers posed by marine debris were becoming evident to some people, including Charles G. Moss, a Sea Grant marine agent in Brazoria County, Texas.

Mustering the Troops

"The number one attraction in Brazoria County is our beaches," says Moss. "We don't have Astroworld or Six Flags.* We have Surfside. And we have to keep it in shape." Moss began preaching stewardship of Texas beaches in the mid-1970s, when he and a party of volunteers rebuilt dunes flattened by hurricanes, and then stabilized them with grass plantings. They had hoped the dunes would act as barriers against erosion, and prevent marine debris from blowing inland. The dunes performed beautifully on both counts. That, however, presented the party with a new problem—a narrow, very trashy strip of sand. So they did the right thing. They cleaned it up.

During the 1980s Moss expanded his corps of volunteer sand sweepers by persuading

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*Names of amusement parks.

Coastal tourism is a $4.5 billion industry in Texas, which explains why coastal cities and counties are willing to spend $14 million annually to remove garbage from the beaches. Most of the litter comes from trash dumped at sea, contrary to what this Spring Break beach scene on Mustang Island suggests. (Photo courtesy of Marine Advisory Service, Texas A&M Sea Grant College)

groups to adopt and maintain one-mile stretches of beaches. The Texas Adopt-A-Beach Program and the statewide September Coastal Cleanup Day are outgrowths of this work. These efforts are helped along by the 140 talks he gives annually at elementary schools, meetings of service organizations, and wherever else he is invited. Of the 370 miles of beach on the Texas Gulf Coast, 113 have now been adopted. In their February 1988 bulletin, the Washington D.C.-based Center for Environmental Education (CEE) reported that more than 7,000 volunteers came out for the 1987 Texas Coastal Cleanup on September 19th. More than 400 of these "Beach Buddies" were from Moss's Brazoria County corps. During the 3-hour cleanup, volunteers collected more than 300 tons of trash from 157 miles of beach–about 2 tons per mile.

Two subjects Moss always addresses in his talks are the harmful effects of marine plastics and the case against littering. He believes there are three reasons why people litter:

- *They do not care;*
- *They regard litter as a fact of life; or*
- *They expect somebody else to clean up after them (the "mother syndrome").*

He admits that regular beach cleanups may reinforce the mother syndrome for some litterbugs, yet he has seen people and communities become more responsible as his educational message hammers home. "Education is definitely the key." He concludes: "Otherwise you're nothing but a garbageman."

Moss also recognizes that the leavings of beachgoers form a minor component of the debris on Texas shores. He acquired first-hand proof of this when one mile of an adopted beach was cleaned up at dusk, and, the next morning, he helped collect another 167 pounds of nonbiodegradable trash that had washed ashore overnight. **(continued page 34)**

The Marine

At left, Lucky, a trained dolphin, prepares to hurl a plastic pop bottle at a litterbug boater. This example of nature striking back was telecast in a public service announcement produced by Texas Sea Grant and the State General Land Office. (Photo courtesy Texas General Land Office) Other credits: above, photo by J. Domont; below, photo by R. Herron; near right, courtesy of Center for Environmental Education; lower right, courtesy of Center for Environmental Education; upper right, courtesy of Center for Environmental Education.

Debris Problem

Sources of Debris

Data from Texas beach cleanups, and from Sea Grant-supported monitoring studies of beach debris on nearby Mustang Island indicate that 75 to 95 percent of the state's beach trash originates from offshore sources, primarily from the shipping industry. This agrees with a report by the National Academy of Sciences*, which says that most marine debris comes from merchant ships and passenger vessels, with less from recreational boats, commercial fishing boats, and military vessels.

Some of the sources of Texas debris did turn out to be eye openers. It was discovered that the U.S. Navy generated three pounds of trash per sailor per day, which it put in bags and jettisoned. (The bags were punched with holes to make them sink; no doubt this is an example of our throwaway society's "dispose of properly" mentality in action.) Conversely, oil rigs and platforms accounted for very little Texas trash, even though they are widely believed to be major contributors because of their conspicuousness.

Informing the Public

About five years ago, Texas Sea Grant began working with the State General Land Office to develop news releases, public service announcements, and videos that document the causes of marine debris, and suggest corrective measures. Out of their collaboration has come a video, titled "Trashed-Out Texas Beaches." This details the magnitude of the debris, calls for specific legislation, and even gets the support of a country rock band. It has been shown not only around the Gulf States, but at U.S. Congressional hearings on the need for better regulation of offshore dumping.

On a lighter note, a 30-second video features Lucky the dolphin retrieving a plastic pop bottle seconds after a pleasure boater has tossed it overboard, and then heaving it back at the offender. The direct hit is followed by a warning from musician Joe "King" Carrasco: "Trash over the side means trash on the beaches, and my friend Lucky is tired of it. So, hey! Don't mess with Texas beaches." Presentations, feature stories, beach cleanups, beach adoptions, debris investigations, legislative pressure, humor—Texas Sea Grant is taking a multifaceted approach to the marine debris problem.

Extension Activities Elsewhere

All 30 programs in Sea Grant's Advisory Service have entered into the campaign against marine plastics. For many, their work has just begun, which is understandable since plastic production has doubled worldwide in less than 10 years (the industry now uses 22 million tons of resin annually to create its products). The more recently enlisted programs are generating news releases, publishing articles on marine debris in their newsletters, and distributing informational materials produced by the National Marine Fisheries Service, the Center for Environmental Education in Washington, D.C., the U.S. Fish and Wildlife Service, Defenders of Wildlife, and other organizations. Because the problem is global, and the categories of pollution are many, the degree of cooperation will ultimately determine the degree of their success.

Work of longer standing has produced a higher profile in several other states. Sea Grant extension programs in North Carolina, Louisiana, Georgia, Massachusetts, and Oregon are acquiring reputations as centers for resource materials on marine debris. These materials include slide shows, posters, radio spots, brochures, videos, extensive bibliographies, and a clippings service. The programs also have speakers available for classroom presentations and for expert testimony before legislative bodies.

Many marine extension programs have helped organize beach cleanups in their states. Following the lead of Texas, the programs of Georgia, North Carolina, and Louisiana are compiling computerized data on the nature and origins of nonbiodegradable materials gathered during these cleanups, data that they find especially useful for preparing legislative testimony. While it is true that, globally, merchant ships are the major source of marine debris, there are regional differences. Commercial fishing vessels generate the lion's share in the northeast Pacific, for example; and sewage outfalls and garbage scows may be the major polluters of the shores of New York and New Jersey, where excessive debris wash-ups were reported in the summer of 1988. Knowing the identities of the big dumpers prevents unwarranted testimony in support of every bill that comes down the pike.

Much of the marine-debris work of Sea Grant extension programs is still in the alarmist stage. Before the public can react to an environmental crisis, it must be made aware of it. But because crises are the regular fare of our daily press, the public has become more difficult to arouse. "Sure," says John or Mary Q. Citizen, "porpoises, sea turtles, and pelicans are dying like flies because of nets that trap and plastics that poison them. Sure, sure, we know all about it. And Ethiopians starve while rats get fat on gifts of U.S. grain, and the last seven condors are living in bird cages. Well, it's a rough life, and few are lucky enough to get out of it alive."

Perhaps such jaded individuals would prefer to skip the alarmist and go directly to the resolution stage of our environmental crises. In that case, they should be conscripted immediately to participate in the closest beach cleanup. And while they are productively occupied, they should be told about the miracle in Newport, Oregon.

Fishermen Behave Strangely

Newport is a seacoast town of 8,000 people at the

*Assessing Potential Ocean Pollution, 1975.

mouth of the Yaquina River. Although tourism has become big business there in recent years (its population may jump from a resident 8,000 to 30,000 on a good summer day), historically the town's economy is linked to fisheries, and to a lesser extent, the wood products industry. Salmon trollers, charter boat operators, bottomfish trawlers, shrimpers, and crabbers call its working waterfront home, where facilities exist for 800 vessels. At the marina across Yaquina Bay, there are another 600 slips for recreational boaters.

In 1987, a peculiar behavior swept through this community of fishermen. They began returning to port with bags of compressed garbage, which they deposited in bright blue dumpsters marked for recyclables (metals, wood, netting, cardboard) and nonrecyclables. They wore blue sweatshirts and caps emblazoned with the logo of a fish trapped in a plastic six-pack yoke and the message:

DON'T TEACH YOUR TRASH TO SWIM!

These fishermen-turned-ecologists also made public service announcements on radio and TV, urging their peers to bring refuse back to port, and to retrieve the floating debris of others before it could harm wildlife, or put vessels out of commission. Some of them even paraded around town shrouded in cast-off nets to emphasize their point.

Such commendable, if aberrant, behavior came about because of a pilot project funded by the National Marine Fisheries Service Marine Entanglement Program and administered through the Port of Newport. The project's director, Fran Recht, worked with the port to provide facilities for shoreside disposal and recycling of marine debris. She also met fishermen on the docks, where her query: "What do you have for me today?" brought her a lot of garbage. Perhaps five feet tall, the former Peace Corps volunteer is irrepressible and sincere, and the fisherman took her to heart.

Genesis of the Project

Recht's refuse disposal project grew out of a 1986 symposium held at the Hatfield Marine Science Center in Newport. Titled "The Pacific Ocean and the Plastic Plague: Dealing with Ocean Debris," it was cosponsored by Oregon's Extension/Sea Grant Program, the National Marine Fisheries Service, and commercial fishermen of The Highliners Association. Participants agreed that education was preferable to legislation, and the fishing industry urged Sea Grant to use its network to deliver the cleanup message.

The Marine Entanglement Program, which was created in 1985, then announced its intention to fund a pilot refuse-disposal project at a small port with active sport and commercial fishing fleets. Initially, neither the city nor the Port of Newport was interested in submitting a proposal for the suggested grant. But R. Barry Fisher, a West Coast fisherman, and Ginny A. Goblirsch,

Fran Recht, director of Newport's refuse disposal project, examines old nets left at the recycling station. The nets quickly disappeared, to show up later on gardens, as softball backstops, or hanging from the walls of local businesses. (Photo courtesy of Oregon Extension/Sea Grant Program)

an Extension/Sea Grant agent based in Newport, proceeded to convince them and key fishermen in the community that the project had merit. They also noted that if Annex V of the International Convention to Prevent Pollution from Ships was ratified by the United States, it would prohibit dumping of plastics at sea, and would require all ports to develop dockside waste-management systems to handle vessel refuse.

The port then asked Goblirsch and other Extension/Sea Grant personnel to draft the proposal, which they did. Soon thereafter they hired Fran Recht to direct the $97,000 project.

Winning Over a Community

In designing the project, Goblirsch and Recht began with the premise that the fishing community would be more apt to participate if it had ownership in solving the marine debris problem. So they built an advisory council comprised of key commercial and recreational fishermen, plus representatives from the Fishermen's Wives, the Coast Guard, the Coast Guard Auxiliary, Sea Grant, a fish-processing plant, a charter boat office, and the marina. To give the council land-based perspectives as well, they brought in the owner of a refuse company, the recycling coordinator for the county, the president of the Newport Chamber of Commerce, the director of the state Coastal Zone Management Association, and representatives from the city, port, sheriff's department, state police, local school system, and state Department of Fish and Wildlife. It was an advisory council that went from the waterfront to the water tower and beyond. Its members carried no rubber stamps—they were there to critique and suggest ideas. And once they were sold on the project, they began selling it to the community.

The Newport project produced materials as

well as a successful strategy. The materials included:

- *Several radio and television public service announcements;*
- *A video, rich with waterfront testimonials;*
- *A color brochure illustrating the ways marine plastic affects wildlife;*
- *A traveling exhibit on marine plastics, first displayed at the Hatfield Marine Science Center;*
- *Documentation of how much money recycling saved the Port of Newport;*
- *Documentation of fishermen's encounters with marine debris, and the costs incurred; and*
- *A slide/tape show on marine plastics and wildlife, distributed through the National Association of Marine Educators.*

The Marine Refuse Disposal Project soon attracted media from the entire Northwest region, and was featured in magazines, newspapers, and television specials many times in 1987. It also caught the attention of the state of Washington, where the Puget Sound Water Quality Authority awarded $30,000 to Washington Sea Grant to conduct a similar port project in Bellingham.

Exporting a Success

Now, the waterfront shack where Fran Recht operated has been razed to make way for dumpsters and a better recycling station. As for the materials generated by the project, they are being packaged by Goblirsch for distribution to other ports and Sea Grant programs. It appears the ports will be needing them. Last December, the United States ratified Annex V of the International Convention to Prevent Pollution. When it takes effect on December 31, 1988, all ships will be prohibited from dumping plastics at sea, and ports must prepare shoreside facilities for wastes.

The prospect of Annex V prompted a meeting last February in Portland, Oregon, to address problems caused by fisheries-generated plastic debris and derelict fishing gear. Organized by Alaska Sea Grant at the request of the White House Domestic Policy Council, the meeting drew fishermen, port managers, gear manufacturers, researchers, Sea Granters, plastics industry representatives, and government officials.

They were particularly concerned with ghost-fishing gear—that is, with lost or abandoned pots, which may destroy fish and wildlife indefinitely, and nets, that may take from weeks to months to ball up and finally sink. Almost none of the suggested solutions to ghost fishing found favor among the participants. Biodegradable nets, fines, and such incentives as refunds for returned gear were called technologically impossible, unenforceable, and absurd.

Participants at the meeting did favor one approach, however. They wanted more educational work, done along the lines of the Newport project. They praised it for being positive rather than punitive; and, best of all, it really did reduce marine debris. Mark Twain–like Lord Byron, a quotable mariner given to salty observations—might have agreed with their choice. As he once put it, "Soap and education are not as sudden as a massacre, but they are more deadly in the long run."

Dan Guthrie is a marine specialist with the Oregon Extension/Sea Grant Program, and Assistant Professor in the Department of Fisheries and Wildlife at Oregon State University.

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Beach Cleanup Info

For information about how to start a beach cleanup in your area contact Patty Debenham at the Center for Environmental Education, Washington, D.C. (202) 429–5609.

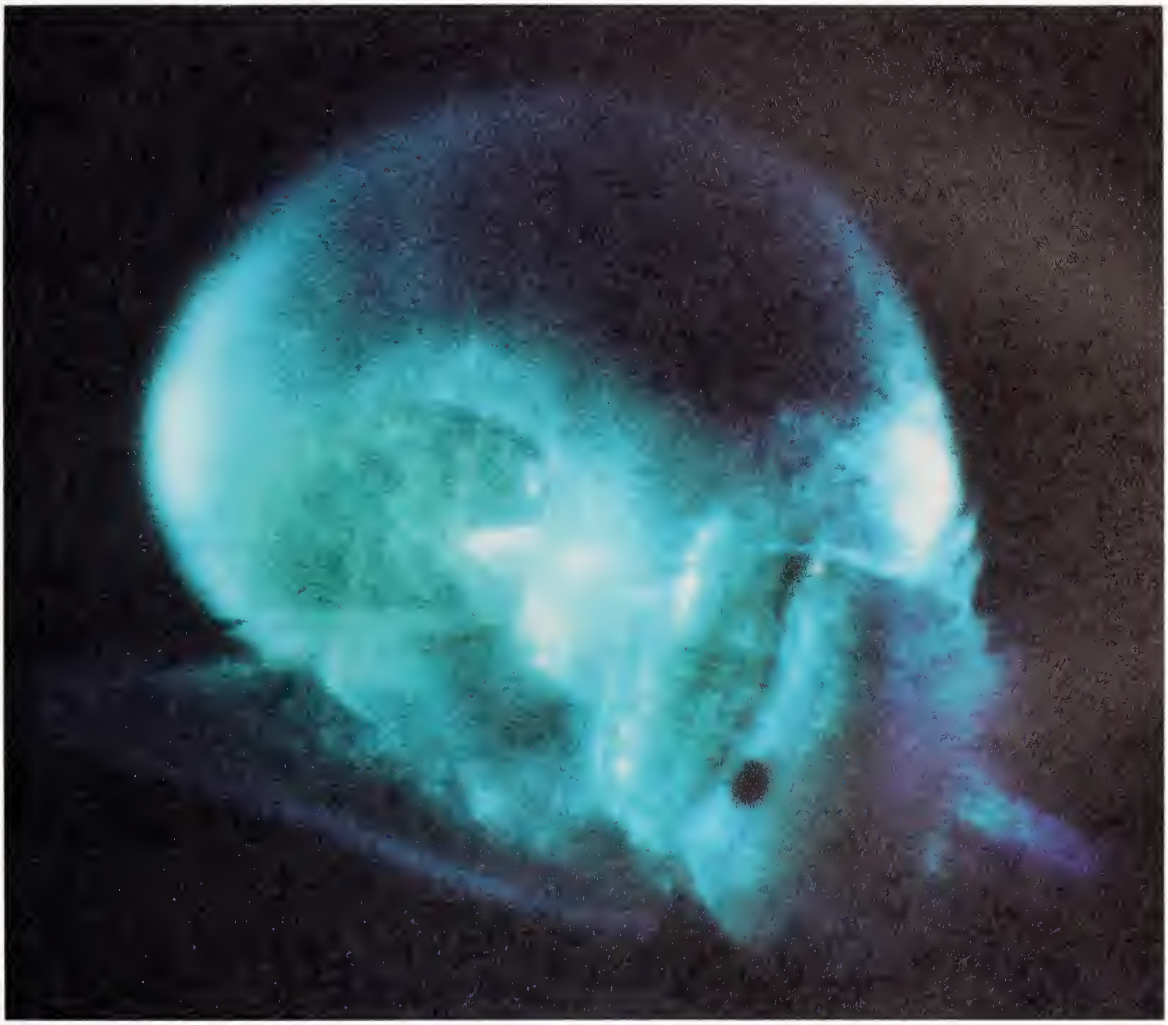
Info on Plastics

Selected papers from the 6th International Ocean Symposium are compiled in the June 1987 issue of *Marine Pollution*, Volume 18/ No. 6B. The 62-paged issue is entitled, "Plastics in the Sea." Copies are available for $14 each, plus $2 postage and handling, from:

Marine Pollution Bulletin
Pergamon Press, Inc.
Maxwell House
Fairview Park
Elmsford, NY 10523
(914) 592–7700

Chemical Signals and Molecular Mechanisms:

Learning from Larvae



by Daniel E. Morse, and Aileen N. C. Morse

One of the most dramatic adaptations to life in the oceans is the production of millions of tiny, planktonic larvae by many marine animals. These larvae are dispersed in the oceans' currents to find new and favorable habitats before they settle and metamorphose to the adult form. The processes of reproduction, larval dispersal, and metamorphosis previously were thought to be largely passive, controlled only by climate and the large-scale movements of ocean waters.

However, all these processes are now known to be controlled, to a surprising degree, by specific chemical signals in the environment.

All organisms, and some inanimate objects, release chemicals into their surrounding environment. If any such chemical is used by an organism to convey information—such as the presence of food, mates, or suitable habitat—it can be called a chemical signal. Sea Grant-sponsored research is leading to the identification, and in some cases even the harnessing, of chemical signals that control the reproduction, dispersal, recruitment, and development of diverse marine organisms—from shellfish to reef-building animals. The animals relying on such chemical signals include many valuable species that are harvested for food, and medical and research products. Barnacles and shipworms, which cause serious economic damage by fouling ships, pipes, and oil rig platforms, also use chemical signals. Research into the identification of these signals, and the molecular mechanisms controlling their production, is already yielding practical benefits.

Chemical Signals Control Spawning

The authors' studies began with the abalone, a large and valuable marine snail, highly prized for its meat and shell. Annual sales of this gastropod mollusk total approximately $500 million worldwide; the resulting heavy pressure by the world's fishery on this resource has led to a steady decline in supply, and increasing interest in developing more efficient methods of commercial cultivation.

Taking a clue from abalone divers in California, who reported seeing the occasional mass spawning of abalones on submerged reefs, laboratory studies showed that abalones do respond "contagiously" to the spawning of nearby individuals. A chemical released with the spawn triggers the release of gametes by neighbors of the same species. The chemical responsible for this induction of spawning is a small molecule known as a prostaglandin (so named because this sort of molecule was first discovered in the human prostate gland). Although the presence of prostaglandins is known in widely distributed terrestrial animals, and some marine animals, this was the first evidence that they play a role in the control of reproduction in marine organisms. The authors, along with Tadashi Nomura at Tohoku University in Japan, have found that many marine species use prostaglandins in this way.

Over, title photo shows a larval abalone, attached by its foot to a glass surface, minutes after being induced to settle from the plankton and begin metamorphosis to the adult snail by exposure to a neurotransmitter-like peptide purified from red algae. The peptide triggers metamorphosis by binding to specialized chemosensory receptors on cell membranes of the larva. This peptide also binds strongly to receptors on nerve cells in the mammalian brain, suggesting possible applications for medical use.

By adding a trace of prostaglandin to the surrounding seawater, both male and female abalones can be induced to spawn. Prostaglandin is, however, an expensive chemical to use on a large scale, as in aquaculture. The authors searched for a less expensive method, and found it possible to tap into the animal's normal process of internal prostaglandin production. In abalones, prostaglandin is synthesized in the gonads. The first critical reaction in its synthesis is catalyzed by an enzyme, which is in turn regulated by minute concentrations of hydrogen peroxide.

Taking advantage of this finding, simply by adding a small amount of hydrogen peroxide to the surrounding seawater, the abalones were induced to spawn, releasing millions of eggs or sperm. This method is easy, inexpensive, safe, and very reliable. It works well for many species of abalones, oysters, scallops, mussels, giant clams, and other mollusks. Because it is so easy, this method now is used widely in California for the production of abalone in hatcheries; it is also used in abalone and mollusk cultivation programs around the world. Because this method works by activating the production of the natural spawning trigger, the eggs and sperm obtained by this method are normal, healthy, and fully capable of fertilization, producing normal embryos that hatch to yield millions of healthy, swimming larvae.

Signals Required for Metamorphosis

Swimming abalone larvae also require a chemical signal from the environment before they can metamorphose into mature, bottom-dwelling snails. This has proven to be the case not only for abalone, but also for other marine species.

When abalone larvae are cultivated in clean seawater, they develop in about one week to the point where they become "competent," or capable of undergoing metamorphosis. Development remains arrested at this point, however, and no metamorphosis occurs; instead, the larvae alternately swim and sink through the water for as long as one month, until they eventually exhaust their supply of yolk, and die. The larvae thus seem to require some stimulus or signal that induces metamorphosis—a signal that they normally find in the natural environment, but that is absent from the clean seawater in the artificial cultivation system.

With Mia J. Tegner of the Scripps Institution of Oceanography, the authors found that the smallest juvenile abalones are found almost exclusively on certain species of red algae that commonly form a crust on submerged rocks. When these algae, called crustose coralline red algae, are presented to the abalone larvae, the larvae are quickly induced to settle, attach to the algae or some nearby surface, and begin metamorphosis. It is necessary for the larvae to actually touch the algae for the induction of metamorphosis to occur; the basis for this contact-dependence is chemical recognition by

A male abalone (18 centimeters in length) is shown releasing sperm in response to hydrogen peroxide. The sperm are broadcast in jets of water expelled through the respiratory pores in the shell. As many as 10 trillion sperm may be released during a period of 30 minutes in a single spawning. Female abalone also are induced to spawn copiously by this simple and inexpensive method.

the larvae of a signal molecule, uniquely available at the surfaces of the crustose red algae.

To activate the genetically programmed sequence of events leading to metamorphosis, the signal molecule must bind to specialized receptors on the cells of the larvae. If the larvae fail to detect this signal, their development remains arrested, and they eventually die. This mechanism of signal recognition thus ensures that the recruitment of larvae occurs only in favorable habitats. The recognition by these larvae of the algal signal molecule explains the specific distribution of recruitment, on crustose red algae around the world, for many different species of abalone.

Working with Christopher L. Kitting, now at California State University at Hayward, the authors showed that the relationship between the recruiting algae and the grazing herbivorous mollusk is truly symbiotic and mutualistic (that is, mutually beneficial to both the plant and animal partners). The abalones benefit not only by being induced to metamorphose on the algal surface, however; the algae are also a source of microalgae suitable for the young animals' diet, in addition to being a source of camouflaging red pigment incorporated from the algae into the animals' shells. The algae, in turn, benefit from the shallow and non-destructive grazing by the juvenile abalones, which keeps the red algal surface free of filamentous algae; so the grazing actually promotes the growth of the crustose red algae.

The chemical signal produced by the red algae that induces abalone larvae to settle and metamorphose is a newly discovered kind of peptide (a small protein-like molecule) with remarkable similarity to the neurotransmitter* known as GABA (gamma-aminobutyric acid, which transmits information among 40 percent of the neurons in the human brain). For this reason, the metamorphosis-inducing molecule is called a neurotransmitter-mimetic (or GABA-mimetic) peptide.

Contact of the abalone larvae with the GABA-mimetic peptide purified from the red algae, or with GABA itself, quickly induces them to cease swimming, settle to the bottom, attach, and metamorphose to the adult form. The metamorphosis induced by the GABA-mimetic peptide is indistinguishable from that induced by the intact alga; the larval ciliated swimming organ is shed, the shell-secreting tissue grows and starts functioning, and the heart and other internal organs complete the differentiation that had been arrested at the larval stage. Because GABA is an inexpensive amino acid and readily available, this discovery also is being used to improve the economic efficiency of abalone and other shellfish production by aquaculturists in

*A chemical released in minute amounts by the endings of nerve cells. Its release causes adjacent nerve cells to carry signals, or adjacent muscle or glandular cells to become activated.

Scanning electron micrograph of a fully developed abalone larva (0.2 millimeters), ready to settle and begin metamorphosis. The many long cilia surrounding the face are the larval swimming organ; the foot and shell cover are held in curled positions beneath the head. The sensory tentacle buds and short sensory cilia project from the face; these detect the chemical signals that induce settlement and metamorphosis.

the United States and abroad. Steven L. Coon and Dale B. Bonar at the University of Maryland have found recently that a similar amino acid neurotransmitter, known as DOPA (dihydroxyphenylalanine), can be used to induce efficient metamorphosis in oyster larvae.

Using GABA-mimetic molecules tagged with a radioactive tracer, the larval abalone receptors that bind the inducer have been labeled, and so have begun yielding some of their secrets. These are the first receptors controlling the settlement and metamorphosis of any marine animal to be directly labeled and characterized in this way. The resulting studies have provided the most detailed understanding yet available about the cellular and molecular mechanisms by which chemical signals and larval receptors control the life cycles of marine organisms, and mediate their interactions with the environment.

These studies have shown that once the signal molecule is bound by the larval receptors, a cascade of enzymatic reactions is stimulated, leading to the production of an internal "second messenger" that in turn activates an enzyme that causes the opening of tiny channels in the membrane of the receptor cell. When these channels in the cell membrane are opened, negatively charged chloride ions rush out (Figure 1). The exit of chloride ions changes the net electrical charge across the membrane, or "depolarizes" the cell. The depolarization causes an electrochemical signal to be sent to the larval nervous system. The activated nervous system then transmits these signals to the brain, which coordinates the behavioral and developmental changes, resulting in settlement, cellular differentiation, metamorphosis, and the renewal of growth. Interrupting any step of this process—the original binding, the enzyme cascade, the depolarization, or the nervous system activation—will halt the metamorphosis.

Very similar signal molecules, receptors, and mechanisms of signal transduction control the settlement and metamorphosis of the larvae

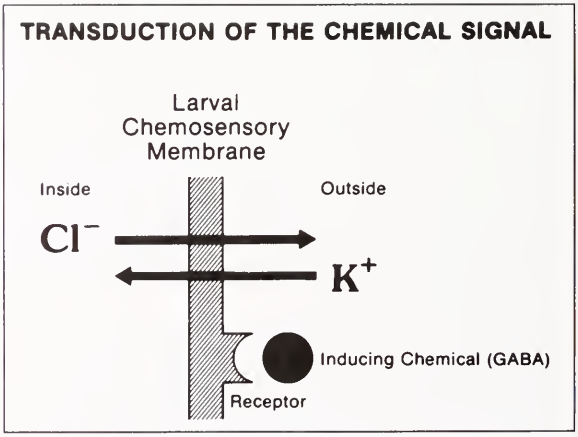


Figure 1. The basic mechanism controlling settlement and metamorphosis in abalone and many other mollusk larvae: Chemical signals present in the environment (such as GABA-mimetic peptides from certain algae) bind to receptors on sensory cells of the planktonic larvae. This external binding triggers a cascade of internal events, culminating in the opening of chloride (Cl^-) ion channels in the cell membrane. Ions rush out through these opened channels, depolarizing the cell. The inducing chemical signal from the environment is thus transduced, or changed, to an electrochemical signal that is sent via the larval nervous system to its brain.

of a number of other species. In cases where the identity of the required signal is not yet known, it is possible to by-pass the normal signal and receptor, simply by exposing the larvae to slightly elevated concentrations of potassium ion. This causes direct depolarization of the receptor cell membranes, thereby inducing larval metamorphosis. This simple and inexpensive method works well to induce metamorphosis in abalones and a number of other invertebrates, and so could prove to be useful in aquaculture. These findings also are already proving useful in efforts to develop new methods to block the metamorphosis of undesirable fouling organisms, simply by blocking steps in the transduction of the metamorphic signal, without the use of the highly toxic substances presently employed (see *Oceanus* Vol. 30, No. 3, pp. 69–77).

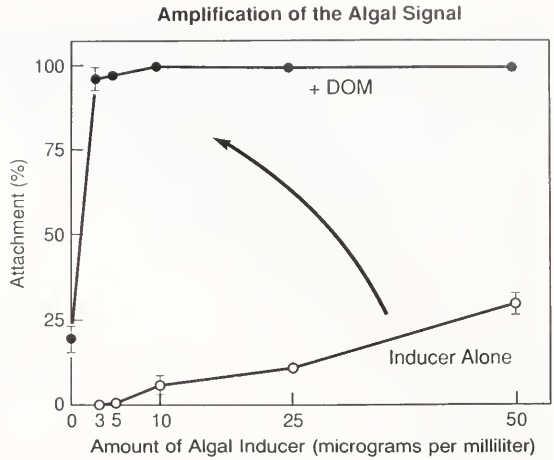


Figure 2. Multiple chemical signals regulate larval metamorphosis. This is shown by the amplification of the effect of the algal signal caused when specific amino acids are present in the dissolved organic material (DOM) in seawater. The percentage of abalone larvae induced to settle, attach, and metamorphose in response to low concentrations of the GABA-mimetic peptide from red algae is greatly increased by exposure to diaminopropionic acid in the DOM.

Multiple Signals Control Metamorphosis

While the metamorphosis-inducing signal is required for settlement of abalone larvae, the larvae are further guided in their choice of settlement sites by another form of chemical signal in the ocean. Recognition of certain amino acids, present in the dissolved organic material of the water column in very low and variable concentrations, can amplify the sensitivity of the larvae to the GABA-mimetic peptide. The presence of these amino acids in the water can increase the responsiveness of the larvae to low concentrations of the algal peptide by as much as 100 fold (Figure 2).

Experiments by Henry G. Trapido-Rosenthal and Gregory I. Baxter have shown that the amplifier signal is recognized independently, involves a second set of receptors, and has its own pathway of signal processing. The independent pathway is understandable if the presence of certain amino acids in the water column serves as an indicator of the quality of the larger-scale environment, possibly reflecting the availability of nutrients in the water. Recognition of these amino acids by larval receptors in the second pathway can "prime" the larvae, and regulate their sensitivity to the primary algal inducers in potentially favorable areas. The fine-scale spatial specificity of settlement and metamorphosis, on particular algal surfaces, would then be controlled by the availability of the GABA-mimetic peptides. If other marine species follow a similar, two-stage, method of larval settlement regulation, large population outbreaks—such as those of the Crown of Thorns starfish (see *Oceanus* Vol. 29, No. 2, pp. 55–65)—may be explained.

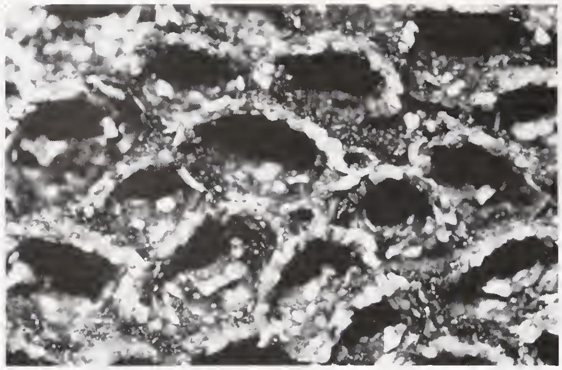
Signals for Reef-Building Species

Signal molecules and larval receptors similar to those of abalone also control the site-specific larval settlement and metamorphosis of many reef-building animals, including certain tube-building worms and tropical corals. Because the tube-building organisms and corals become permanently attached to the sites on which they settle and metamorphose, it is possible to experiment with these animals in the natural environment, and bridge the gap between molecular biology and field ecology.

Rebecca A. Jensen, a graduate student at the University of California, Santa Barbara, found that the larvae of the gregarious tube-building sand-castle worms, genus *Phragmatopoma*, recognize a chemical cue in the cement secreted by the adults as they build their tubes. The requirement of the planktonic larvae for a chemical signal produced by the adults of the same species helps to explain the recruitment of large aggregations of these animals, leading to the formation of massive reefs, or fouling communities, composed of millions of individuals.

Interestingly, the cue recognized by the *Phragmatopoma* larvae is a portion of the adhesive polymer produced by these animals, and is related to the neurotransmitter, DOPA. With J. Herbert Waite at the University of Delaware, Jensen found that this adhesive combines the structural features of a marine epoxy-like cement with the strong tensile strength of the fibrous protein, silk. Its active portion is thus very similar to the GABA-mimetic peptide described for the abalone larvae, despite the fact that the source of the inducer is very different. Another similarity to the control of abalone larval metamorphosis is that a second messenger and membrane depolarization also mediate transduction of the metamorphic signal in *Phragmatopoma* larvae.

The sand-castle worm, Phragmatopoma. *The feeding tentacles are seen projecting from the tube-like dwelling the animal has built by cementing sand grains (Photo courtesy of Robert Sisson,* National Geographic*)*



Massive concretions and reefs weighing many tons, and extending several meters or even kilometers, result from the gregarious recruitment of the cementing tube-building worm Phragmatopoma. *These concretions can present problems of marine fouling and hazards to shipping. The gregarious recruitment of these animals results from recognition by the planktonic larvae of a metamorphosis-inducing chemical signal contained in the cement produced by the adults of the same species. (Photo courtesy of Robert Sisson,* National Geographic*)*

Studies have been extended recently to understand the control of larval metamorphosis of Caribbean reef-building corals. Contrary to the widely held belief that larval settlement and recruitment in these organisms is largely a random process, larvae of four different species of lettuce corals, genus *Agaricia*, can be induced to settle and metamorphose in response to specific chemical signals from the environment.

In the case of the Agariciid corals, the required inducer is found on the surfaces of only a few species of crustose coralline red algae. As with abalone, the requirement for larval settlement and metamorphosis observed in the laboratory has been found to determine the distribution and site-specificity of recruitment of these corals in the natural environment. Unlike the inducer of abalone metamorphosis, however, the inducer of the coral metamorphosis is not a neurotransmitter-mimetic peptide, but is instead a polysaccharide* of the algal cell wall.

Uses in Technology and Medicine

Newly discovered classes of signal molecules regulating the reproduction, larval development, settlement, and metamorphosis of marine animals offers numerous practical applications in addition to the improvements in aquaculture and control of marine fouling already mentioned. An equally exciting area of potential applications lies in the area of human medicine.

The various algal GABA-mimetic peptides that induce metamorphosis in abalone larvae may be useful in designing new diagnostic and therapeutic agents with improved specificity and selectivity for GABA neurons in the human brain and other areas of the central nervous system. Since GABA controls approximately 40 percent of the connections in the human central nervous system, drugs that modulate its activity constitute the largest single group of prescriptions in U.S. medicine today. These drugs control convulsive disorders, muscle function, some types of pain, sleep, and psychiatric state; but their use and effectiveness are complicated by the large number and different sorts of GABA receptors, and by the low specificity of the GABA analogs presently available. This lack of specificity for a single type of GABA receptor also limits applications of recently developed non-invasive diagnostic procedures, such as positron-emission tomography (PET-scan).

The GABA-mimetic peptides purified from marine algae are capable of strong and specific binding to certain types of GABA receptors in mammalian brains. Peptides from different algae behave similarly, but with important differences. Taking advantage of these differences, it may be possible to use the algal peptides as "probes" to map the fine-scale architecture of GABA receptors in the mammalian brain.

Using recent breakthroughs in supercomputer-assisted three-dimensional modeling of molecular structures, it should be possible to correlate the strength and specificity of algal peptide receptor-binding with the peptides' three-dimensional structures, and obtain an accurate picture of the brain receptors themselves. This information then may be used to guide the synthesis and development of a new generation of medically useful compounds for use in PET-scan diagnosis, and improved treatment of brain and other nervous system disorders.

Future Prospects

Many ocean-dwelling animals reproduce to yield millions of tiny larvae that are dispersed by

*A long, complex chain of simple sugar molecules.

Moments after they have settled, abalone larvae begin feeding on the diatoms and other microalgae that cover the red algal surface. The relationship between the abalones and their recruiting algal hosts is mutually beneficial. (Photo from the authors' laboratory, courtesy of Robert Sisson, National Geographic)

drifting and swimming for many weeks in the plankton. For many species, the success of their larvae in settling from the plankton and metamorphosing to the adult form depends on the ability of the larvae to detect and recognize specific chemical signals in the ocean environment. Recognition of these chemical signals, often associated with unique niches or habitats in the marine environment, ensures that the larvae are induced to settle and metamorphose in environments especially well suited for the development and growth of the animals.

Identifying chemical signals in the ocean helps to explain the mechanisms controlling the recruitment of a wide diversity of species in the marine environment. The molecular mechanisms revealed in these studies are providing new insights into the basic ways in which sensory receptors and signal transducers work; how they control behavior, and regulate gene expression and cellular differentiation in response to chemical signals from the environment; and how such pathways of signal recognition and signal transduction interact in neural networks.

These findings also are providing the key to biotechnological developments that already have led to improvements in the cultivation of economically important shellfish. Investigations now underway are aimed at the development of new products for medical diagnosis and treatment of central nervous system disorders.

Daniel E. Morse is Chairman, and Aileen N. C. Morse is a Research Biologist in the Marine Biotechnology Center of the Marine Science Institute, University of California, Santa Barbara, California.

Acknowledgments

The results reported here are from studies that were initiated in 1977 with support from the U.S. Department of Commerce (NOAA) — University of California Sea Grant College Program, and continued with support from Sea Grant, the National Science Foundation, and the U.S. Navy Office of Naval Research. This combined support also made possible the training of ten graduate students, three of whom—Henry Trapido-Rosenthal, Andrea Yool, and Gregory Baxter—made major contributions to this work, and three postdoctoral researchers. We most gratefully appreciate this support.

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Rhode Island Volunteers Monitor the Health of Salt Ponds

by Virginia Lee

The use of trained volunteers for environmental monitoring is an excellent way to obtain certain kinds of reliable data in a cost-effective manner that can be used in research and regulation. Volunteers have a long and honored role in some aspects of science. For example, this year the National Weather Service celebrates the 100th anniversary of a network of volunteers, who record daily measurements of temperature and rainfall all around the country. For years, the Audubon Society has been using volunteers to provide breeding-bird census information. For some 60 years, the U.S. Fish and Wildlife Service has trained volunteers to catch, band, and record sightings of birds, using the resulting information to calculate population dynamics and migratory patterns.

It is, however, only recently that scientists are utilizing this human resource to supplement water-quality monitoring of our nation's surface waters. Within the last decade, a variety of monitoring programs around the country have started to rely on volunteers' measurements of simple water-quality parameters, such as pH or turbidity, in lakes and streams. The training of citizen volunteers to monitor estuaries and tidal waters is even more recent. The water-quality programs are organized in a variety of ways, ranging from those run by private lake associations or citizen activist groups, to those run by state agencies, and those associated with university research projects, such as the Rhode Island Salt Pond Watchers. (In Falmouth, Massachusetts, a pond-watching group, known as Citizen Monitoring of Water Quality in Falmouth Coastal Ponds, was formed recently. It is cosponsored by the Woods Hole Oceanographic Institution's Sea Grant Program and the Town of Falmouth.) The damaging effects of acid rain, changes in the age and size of fish stocks, coastal erosion, eutrophication, and the extent of plastic debris piling up along shores (see page 29), have all been documented with the assistance of volunteers.

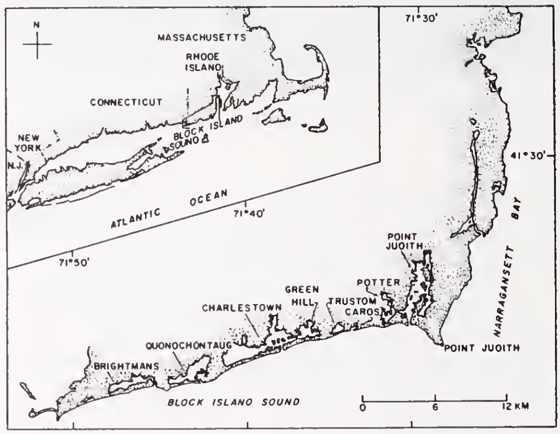
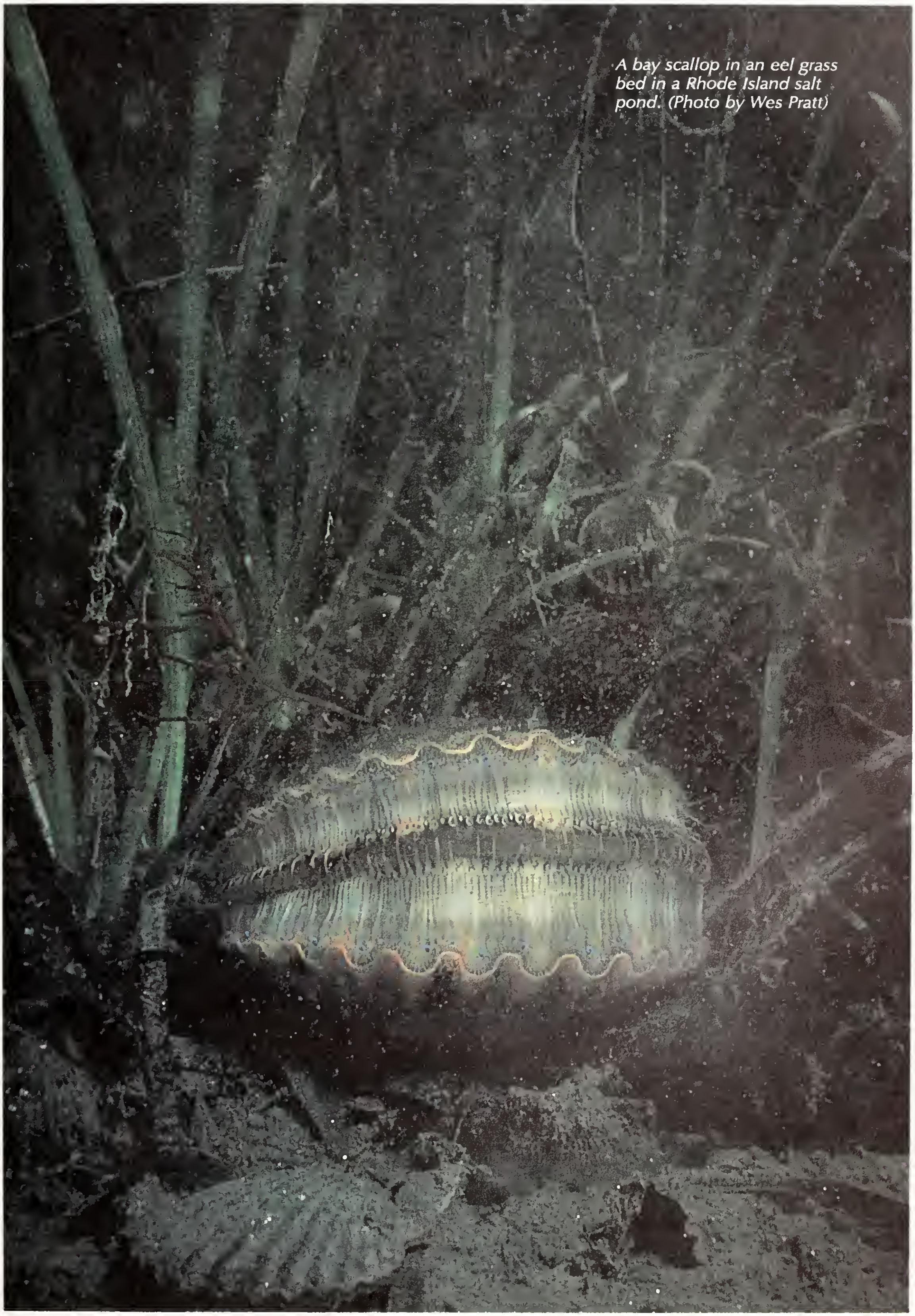


Figure 1. Rhode Island's coastal lagoons, locally known as salt ponds.

Rhode Island's Salt Ponds

Rhode Island's salt ponds are productive lagoon ecosystems. They are shallow estuaries that lie behind barrier beaches along Rhode Island's ocean shore (Figure 1). Sunlight reaches all the way to the bottom, where extensive seagrass (*Zostera marina*) beds, seaweeds, and microscopic aquatic plants abound (Table 1). Connected to the sea by breachways or inlets through the barrier beach, the salt ponds are important spawning and nursery grounds for a variety of finfish and shellfish, including hard clams, soft clams, oysters, and bay scallops. The salt ponds also support intense commercial and recreational fisheries.

In the summer tourist season the salt ponds and their beaches attract in excess of 165,000 people a day, who use the ponds in a variety of competing ways. Examples include aquaculture, water skiing, commercial fishing, recreational boating and marinas, clamming, sportfishing, swimming, and birding. In addition, as most of our nation's coastline moves



A bay scallop in an eel grass bed in a Rhode Island salt pond. (Photo by Wes Pratt)

Table 1. Rhode Island salt pond dimensions.

Salt Pond	Area (km²)	Length (km)	Depth (m)	Salinity (ppt)
Point Judith	6,192	5.5	1.8	30
Potter	1,332	1.1	0.6	28
Cards	174	1.1	0.4	10
Trustom	648	1.2	0.4	4
Green Hill	1,380	1.9	0.8	24
Ninigret	6,924	5.8	1.2	28
Quonochontaug	2,962	3.7	1.8	31
Winnapaug	1,805	3.4	1.5	30
Maschaug	171	0.6	2.1	3

landward, more and more people are moving nearer to the shore, so that residential and commercial development within the watershed is skyrocketing (Figure 2). All these intensifying uses result in some potentially serious water-quality problems, and perhaps even major ecological changes, that may eventually ruin the very resources that the salt ponds now so generously provide.

Salt Pond Watchers

Since 1985, 45 volunteers have been measuring water-quality parameters in seven of Rhode Island's salt ponds. In a Sea Grant-funded project, twice a month, from May through October, pond watchers go out to their stations in boats to take water samples and basic measurements. They not only sample simple parameters, such as turbidity and temperature, but also conduct more sophisticated techniques, such as filtering and storing samples for nutrients, chlorophyll, and bacteria analysis,

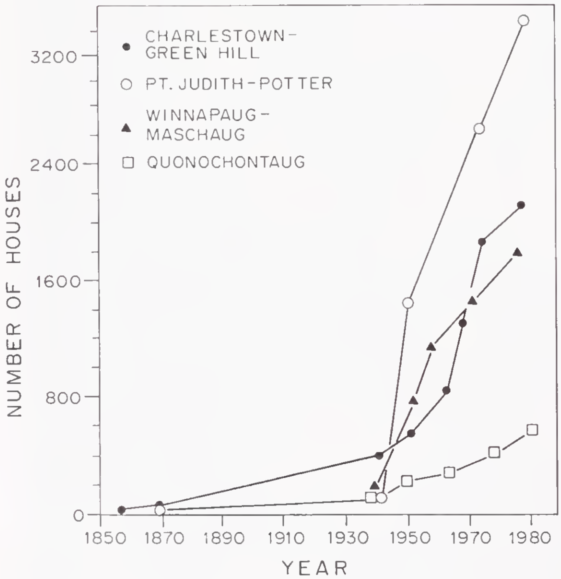


Figure 2. The increase in residential development within the portion of the salt pond watersheds south of Route 1. The trend has been particularly dramatic following World War II and the construction of new highways through the region.

conducting dissolved oxygen titrations, and monitoring evidence of eelgrass-wasting disease. Nutrients, chlorophyll, and salinity are analyzed at the University of Rhode Island Graduate School of Oceanography. Fecal coliform bacteria are analyzed in laboratories at the Rhode Island Department of Health and the federal Food and Drug Administration. The bacteria analysis is donated by these two laboratories, providing an enormous in-kind contribution to the monitoring effort.

Many of the pond watchers, both men and women, are retired. Others have full-time jobs, but are willing to volunteer some of their free time to monitor. All are deeply concerned about the salt ponds. They represent a variety of backgrounds: elementary school teacher, banker, university professor, locksmith, music store owner, realtor, engineer, pediatrician, and contractor. They are proving that volunteers can indeed monitor a variety of water-quality parameters conscientiously, and at a rather high level of sophistication. They are willing to collect samples and record information, in good and bad weather, for years at a stretch, providing their own boats, gas, and motivation. Moreover, their information is already proving useful to government officials for management decisions about the future of the salt ponds and their watersheds.

Pond watchers were recruited from a core group who had participated in an earlier major research project on the salt ponds. In response to public concern about deteriorating environmental quality, a major 5-year, multidisciplinary University of Rhode Island research effort was launched in 1979, with funding from Sea Grant and the Office of Coastal Zone Management. Supplementary monies were provided by EPA and local towns. The pond-monitoring project was designed to clarify many of the major issues and natural processes that are characteristic of the salt ponds: erosion of beaches and sedimentation in the ponds, eutrophication and sources of nutrients from activities within the watershed, limited flushing or tidal circulation, declining fisheries and waterfowl, and economic costs of outdated land-use policies.

Volunteer pond watchers contributed to several of these research projects. They kept waterfowl counts that led to an appreciation of

Salt Pond Watcher Ross Toney samples for bacterial contamination in Potter Pond. (Photo by Virginia Lee)

Pond watcher kit, chemicals, and data notebook. (Photo by Steve Silvia)

the role of the salt ponds as a resting spot during migrations along the Atlantic flyway. They made field observations that helped define the nature of the water-quality problems. They recorded fishing activity, providing an estimate of catch-per-unit effort for the recreational fishery, which turned out to be comparable to commercial fishing in depleting the fish and shellfish resources.

More pond watchers have been recruited by their friends, or have joined the program in response to local press coverage, and annual public meetings where the state of the ponds is discussed.

Providing Useful Information

Pond watchers are providing useful information for government decision making and future scientific research. The bacteria-monitoring effort has provided a successful linkage between the pond watchers and the Rhode Island Department of Environmental Management (DEM), the state agency responsible for measuring water quality and making policy decisions regarding closures of areas to shellfishing or swimming. On the basis of pond watcher data, and some additional field checks, DEM closed Green Hill Pond to shellfishing for the summers of 1987 and 1988. Not only was DEM delighted to have the pond watchers provide extensive field data to use in establishing policy for possible shellfishing closures, they requested that pond watchers assist them in their survey of the shoreline to identify direct wastewater discharges to the ponds.

Another state agency, the Coastal Resources Management Council (CRMC), is responsible for planning and permitting development along Rhode Island's coastal zone. In 1984, it adopted a special area management plan for the salt pond region based on the findings of the multidisciplinary University of Rhode Island salt ponds research project. The plan emphasizes the importance of local initiatives and citizen participation in the management process. As the pond watchers generate a sufficient time series of information, it will be applied in the CRMC permit and planning decisions.

Pond-watcher monitoring results are incorporated into state reports to EPA, on the state of the state's waters, and as a basis for revising the state's construction standards for on-site sewage disposal systems. The towns are using the data to develop policies for special wastewater management districts designed to decrease nonpoint source pollution loads.

Pond watchers also are asked to monitor the impacts of special projects, such as constricted tidal circulation resulting from the 1987 bridge reconstruction over the inlet to Green Hill Pond. Their monitoring indicated that restricted flushing did indeed occur, evidenced by a temporary salinity drop from the usual 23 parts per thousand to near zero for several months (Figure 3). Pond-watcher data proved the wisdom of planning the reconstruction so that it was finished by mid-May. The inlet was then open in time to allow for flounder migration into the pond, and for the increased salinity necessary for the oyster fishery.

Because the pond watchers were asked to start sampling earlier than usual and chop through the ice to monitor the impact of bridge construction, their data disclosed another interesting trend: unusually high concentrations of nitrate and nitrite were seen in the winter, much higher than concentrations normally measured in the salt ponds during other seasons (Figure 4). For the first time we now have evidence of high nitrate loadings to one of the salt ponds resulting from nonpoint sources, principally from lawn and garden fertilizers, and septic systems. This had been predicted by university researchers in the initial multidisciplinary Sea Grant study. When tidal exchange was restricted, Green Hill Pond essentially filled up with stream and groundwater flow, and the high nutrient loadings they carry. When aquatic plants, phytoplankton, algae, and submerged grasses start to grow in the spring using available nutrients, nitrogen concentrations

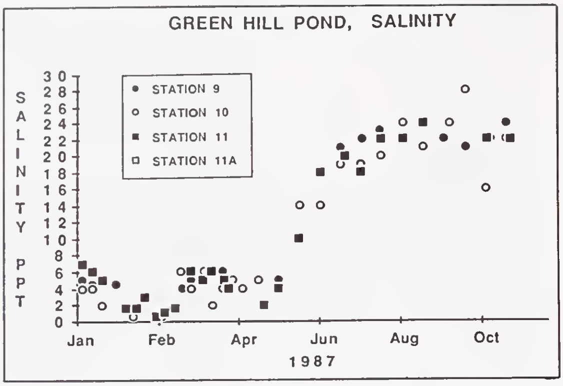


Figure 3. Trends in salinity monitored by pond watchers in Green Hill Pond. The low levels are the result of temporarily reduced tidal flushing associated with bridge reconstruction in the inlet that connects the pond to the sea. When the inlet constrictions were removed in mid-May salinity increased to normal levels of approximately 23 parts per thousand.

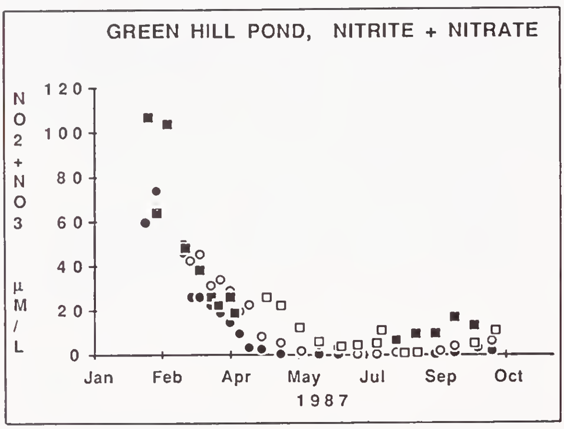


Figure 4. Trends in nitrate and nitrite concentrations in Green Hill Pond monitored by pond watchers. Because of decreased tidal flushing, concentrations exceeded 100 micromoles per liter in the winter when concentrations are normally 10 times less. This is the first evidence of high nitrate loadings from run-off and groundwater contamination resulting from intensifying development and on-site sewage disposal within the region.

decline to the low concentrations typical of the growing season.

As a consequence of these findings, the pond-watcher sampling schedule has been extended throughout the year. The results may now be even more useful to local municipalities in planning improved wastewater management, or altering zoning to reduce pollutant loadings throughout the watersheds of the salt ponds.

Sustaining the Effort

Because of the success of the pond-watchers project, and requests for information from organizations interested in starting citizen-monitoring programs, a symposium for participants from similar programs throughout the country was convened. In late May 1988, administrators and volunteers from almost 100 citizen-monitoring programs gathered at the Narragansett Bay Campus of the University of Rhode Island. This three-day workshop was sponsored by the Rhode Island Sea Grant College Program and the U.S. Environmental Protection Agency. The workshop was the first national forum to focus on the issues specific to citizen monitoring. The ingredients for successful monitoring were defined. Critical to the viability of any program are: 1) identifying what information is needed and how it can be used, 2) obtaining funds and reducing costs, 3) providing credible information, and 4) maintaining motivation and positive feedback. The conference served to infuse new energy into a group of hard-working people whom felt they had been individually battling environmental degradation. A valuable network of program administrators was established, and a sense of unity toward a common goal was fostered.

The Future

The key factor in the success of the Rhode Island Salt Pond Watchers project, and indeed, all the programs across the country, is the people. It is the dedication of the volunteers, and their concern for and their commitment to the environment, that provides a sense of stewardship for the world in which they live. These are the citizens who help maintain the balance between what we take from the environment and what we give back.

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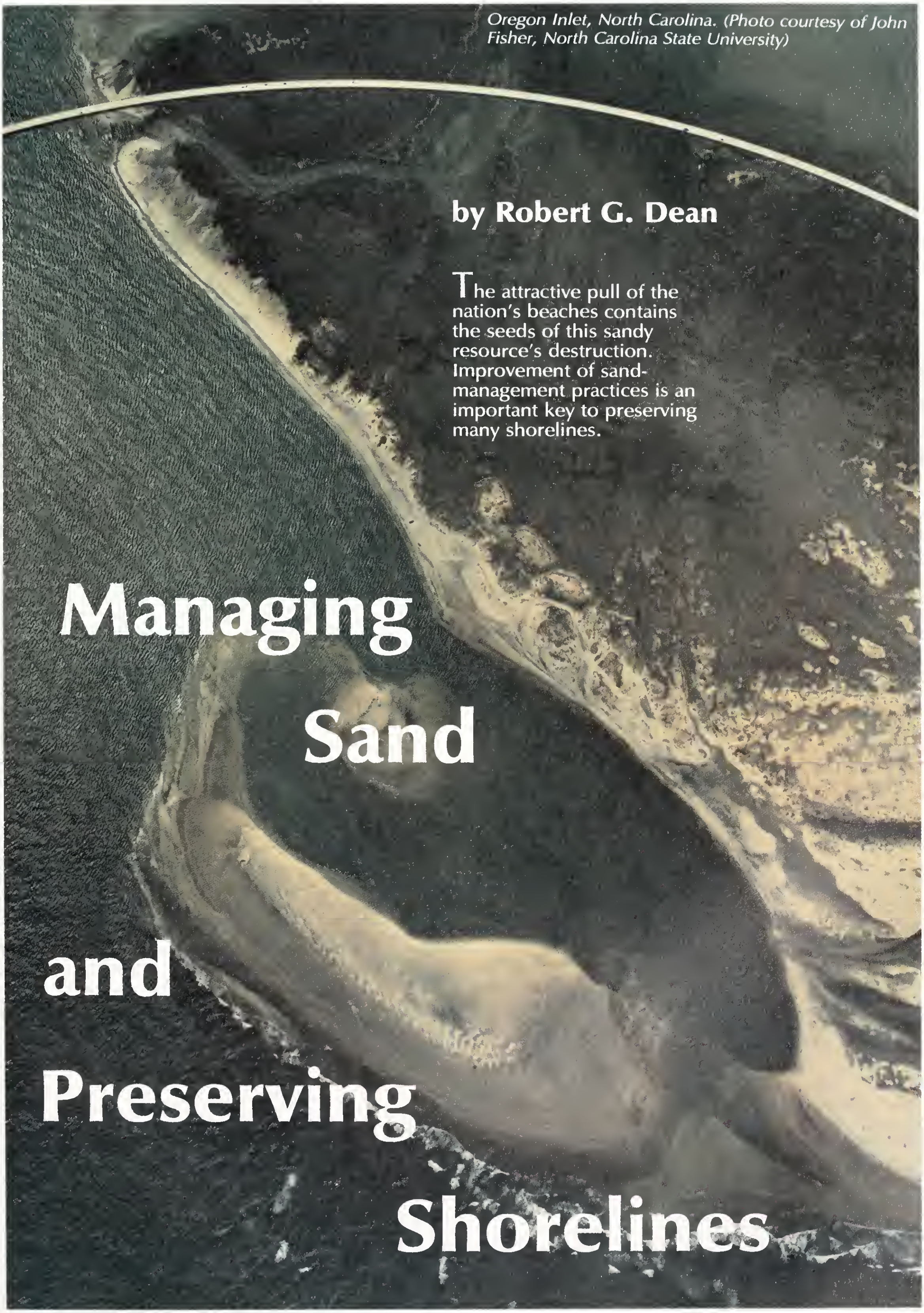

Oregon Inlet, North Carolina. (Photo courtesy of John Fisher, North Carolina State University)

Managing Sand and Preserving Shorelines

by Robert G. Dean

The attractive pull of the nation's beaches contains the seeds of this sandy resource's destruction. Improvement of sand-management practices is an important key to preserving many shorelines.

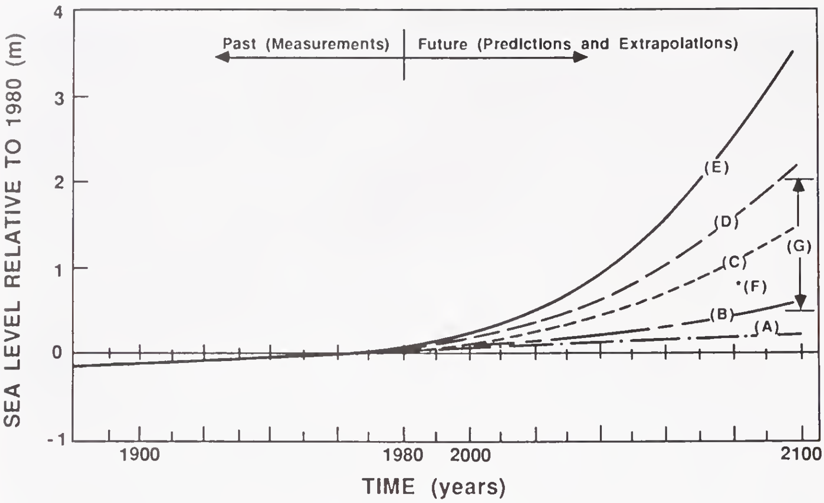

Figure 1. Sea Level Rise. (a) Rate over last century or so, and projected into future. (b), (c), (d) and (e): EPA 1984 estimates for conservative, mid-range low, mid-range high, and high, respectively. (f) Revelle estimate. (g) Polar Research Board augmented with Revelle estimate for thermal expansion.

Many important management questions abound: How near to the shoreline should one be allowed to build? What will be the erosion associated with a long-term rise in sea level, with a 100-year storm? After a storm, will the eroded beach recover, and, if so, over what time scale? What are the effects of various types of coastal armoring, such as groins, revetments, seawalls, and so on? How much erosion is due to navigational channels? If a community spends $10 million for a beach nourishment project, will it vanish in a few months as the protagonists claim?

Through a rational understanding of the response of beach resources to natural and man-made forces, management strategies could be developed enabling appropriate decisions, uses, and development patterns. During the last few decades, the National Sea Grant program has recognized and responded to the need for research to better understand the complicated coastal zone.

With modest but sustained support, and a talented cadre of students, the University of Florida Sea Grant Program has been able to advance understanding, develop new concepts, and proceed to application on several frontier areas in coastal processes. These range from addressing the effects of sea-level rise on natural erosion rates to development of improved breaking wave models.

During the last 15 years, the author's interest in this field has been intensified by opportunities to participate with T.Y. Chiu, who is responsible for establishing Florida's Coastal Construction Control Line. The line delineates the 100-year coastal hazard zone within which the state has permitting jurisdiction. At the outset of this program, the requisite methodology was essentially nonexistent; this need provided guidance to research efforts. Additionally from September 1985 to July 1987, at the invitation of then Florida Governor Bob Graham (now U.S. Senator), the author served as director of the Division of Beaches and Shores of the Florida Department of Natural Resources. The real-world problems encountered in the administration of this division's responsibilities again accentuated the need for an improved basis to address problems associated with preserving the nation's beaches.

Varying Shorelines and Opinions

To manage the coastal zone properly, it is necessary to understand the relevant processes and short- and long-term prognoses for shoreline change. Recent projections of sea-level rise (Figure 1, and see *Oceanus*, Vol. 30, No. 3, pp. 16–22.) have accentuated the urgency to understand shoreline processes. Surprising as it may seem, there are only three human response alternatives to sea-level rise and the erosional pressure that it will bring: 1) retreat, 2) shoreline stabilization by hard structures, and 3) shoreline stabilization by beach nourishment.

A significant descriptive characteristic of our nation's shoreline is its large variability in time and space. Added to this is our rather dismal legacy in documenting and analyzing the performance of quite expensive projects. S.K. May and others (1983) summarized the average shoreline change rates on a state-by-state basis (Table 1). The puzzling variation of 4 meters per year recession in the state of Virginia, to an accretion of 0.7 meters per year for Georgia gives rise to important questions about the causes.

Some areas undergo erosion for periods of years followed by years of accretion. The common perception is that all of our shorelines are eroding in response to sea-level rise and storms, and that anthropogenic effects (works of humans) have a secondary effect.

Studies along the east coast of Florida suggest just the opposite is true, with poor sand-management practices at channels modified for navigation accounting for 80 to 85 percent of the erosion during the last 40 to 50 years. Inadequate documentation of the success or failure of shoreline projects has left an area rich in

Table 1. Shoreline erosion rate based on historical aerial photographs by state and region (May, and others, 1983).

Region	Average Shoreline Change Rate (m/yr)[a]	Standard Deviation of Shoreline Change Rate (m/yr)	Extreme Shoreline Change Rates (m/yr)[a]		Number of Sample Data Points[b]
			Maximum Accretion	Maximum Erosion	
Atlantic Coast	−0.8	3.2	25.5	−24.6	510
Maine	−0.4	0.6	1.9	− 0.5	16
New Hampshire	−0.5	–	− 0.5	− 0.5	4
Massachusetts	−0.9	1.9	4.5	− 4.5	48
Rhode Island	−0.5	0.1	− 0.3	− 0.7	17
New York	0.1	3.2	18.8	− 2.2	42
New Jersey	−1.0	5.4	25.5	−15.0	39
Delaware	0.1	2.4	5.0	− 2.3	7
Maryland	−1.5	3.0	1.3	− 8.8	9
Virginia	−4.2	5.5	0.9	−24.6	34
North Carolina	−0.6	2.1	9.4	− 6.0	101
South Carolina	−2.0	3.8	5.9	−17.7	57
Georgia	0.7	2.8	5.0	− 4.0	31
Florida	−0.1	1.2	5.0	− 2.9	105
Gulf of Mexico	−1.8	2.7	8.8	−15.3	358
Florida	−0.4	1.6	8.8	− 4.5	118
Alabama	−1.1	0.6	0.8	− 3.1	16
Mississippi	−0.6	2.0	0.6	− 6.4	12
Louisiana	−4.2	3.3	3.4	−15.3	106
Texas	−1.2	1.4	0.8	− 5.0	106
Pacific Coast	−0.0	1.5	10.1	− 5.0	305
California	−0.1	1.3	10.1	− 4.2	164
Oregon	0.1	1.1	5.0	− 5.0	86
Washington	0.5	2.2	5.0	− 3.9	46
Alaska	−2.4	2.0	2.9	− 6.0	69

[a]Negative values indicate erosion and positive values indicate accretion.
[b]Total number of 3-min grid cells over which statistics are calculated.

misinformation and diametrically opposed positions. The Miami Beach restoration project, constructed during the 5-year period 1976 to 1981, comprised the placement of 10 million cubic yards dredged from offshore at a cost of more than $60 million. However, no monitoring program has been conducted, and no reports have been issued to document the physical performance of this project!

Effects of Sea-level Rise

The most pervasive erosional force exerted on the coastal zone is that due to sea-level rise. An equation known as the Bruun Rule represents the shoreline recession due to sea-level rise. The Bruun Rule assumes that seaward of a particular depth, there is no effective interchange with the active shoreward region. This assumption seems innocuous; however, it implies that sediment can only move *seaward* with a sea-level rise.

Practically *all* of the modern barrier islands in the world were formed in the last 6,000 to 7,000 years, a time of sea-level rise, albeit reduced relative to the preceding 18,000 years or so. This suggests that substantial shoreward sediment transport *must have* occurred during the past 6,000 years. It is not possible to quantify all shoreward and seaward forces acting on a sediment particle; however, it can be shown that the nonlinear bottom particle velocities associated with waves result in an average shoreward net shear stress. Several investigators (Jeffries and Meisburger, 1987; Dean, 1986) have concluded that onshore sediment transport appears to be occurring across the continental shelf to the south shore of Long Island. Other geological evidence indicates that shoreline response to sea-level rise is a locally dependent phenomenon, and much more complicated than predicted by the Bruun Rule.

A possible mechanism for the formation of some barrier islands is illustrated in Figure 2. Onshore forces cause slow shoreward sediment transport. During periods of slow sea-level rise, such as that of the last 6,000 years, this transport is sufficient to form ridges of sand along the shoreline, and to stabilize and increase the volumes through additional sand input. As sea level continued to rise, these ridges retreated some, and the landward area was flooded, forming lagoons and isolating the ridges—transforming them into barrier islands. The average relative stability of Florida's shorelines also supports the concept of additional sediment input into the nearshore region.

Sand Management at Inlets

Man-made effects on shorelines are known to be substantial in many cases, including that of Santa Barbara, California, where a littoral barrier in the form of a breakwater was constructed from 1928 to 1930; Assateague Island, Maryland, where an inlet formed by the severe 1933 hurricane was stabilized and resulted in severe erosion of the north end of the island; and construction of a groin field at Westhampton, Long Island, New

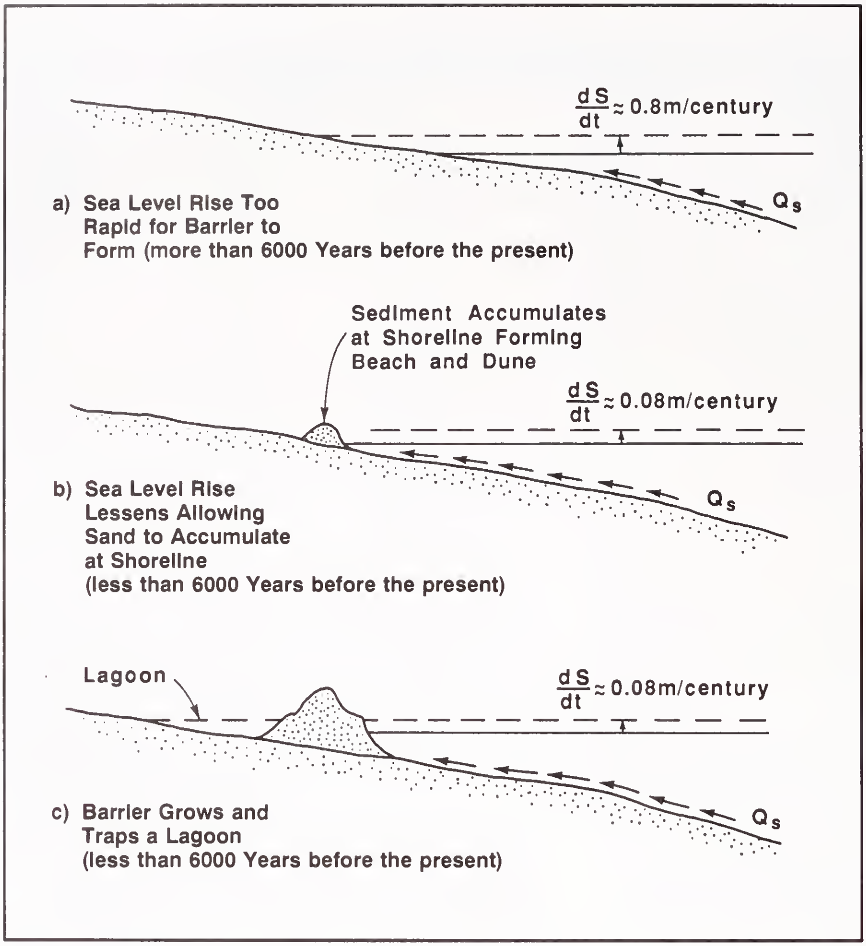

Figure 2. The role of shoreward sediment transport, Q_s, across the shelf, and rate of sea-level rise in causing barrier island formation. (After Dean, 1987)

York, which trapped the westward longshore sediment transport and caused beneficial effects within the groin field and disastrous effects west of the groin field.

Of the 19 Florida east coast inlets from the Georgia border to the southern limits of Miami Beach, all but two have been modified or constructed for navigational purposes. Efficient navigation requires a deep, stable channel, which is usually accomplished through construction of one or more training jetties and periodic dredging as required to maintain project channel depths.

Modified inlets have a number of deleterious effects on the downdrift shoreline, the most obvious of which is sand trapping against the updrift jetty and erosion downdrift, resulting in a very visible shoreline offset. Examples of this offset are presented in Figure 3a for the Port of Palm Beach Entrance, Florida, which was cut in 1918 and in Figure 3b for Ocean City Inlet, Maryland, formed by a hurricane in 1933 and later stabilized by jetties.

Storage of sand against the updrift jetty, and an associated downdrift erosion, redistributes sand in the system to the delight of those located on the updrift side of the entrance, and the great distress of those on the downdrift side. Yet this is not the greatest travesty in past and present sand management practices. During the last 50 years, more than 50 million cubic yards of high quality sand from Florida's east coast inlets have been dredged and disposed of in water too deep to assure its return to the active nearshore system. This sand is considered to have a current market value of $250 to $500 million (about $5 to $10 per cubic yard). Unfortunately this practice of deepwater disposal continues today with approximately 40 percent of sand dredged from federally maintained channels on Florida's east coast disposed of in water judged too deep to benefit the nearshore zone.

The impact of poor sand-management practices on adjacent shorelines is not confined to Florida, although other states, notably California, have demonstrated a much higher regard for this valuable natural resource resulting from harbor construction and maintenance dredging. Two examples of channels where poor sand-management practices occur are Charleston Entrance Channel, with Folly Beach Island being the resulting starved downdrift island, and the Savannah River Entrance, with downdrift Tybee Island receiving the erosional impact.

Figure 3. (a) Port of Palm Beach Entrance, Florida, showing large shoreline offset (construction occurred between 1918 and 1925).

Figure 3. (b) Ocean City Inlet, Maryland, with Assateague Island in the foreground. This inlet was formed by a hurricane in 1933. Subsequent erosion has caused the north end of Assateague Island to retreat landward by its full width.

Principles of Beach Nourishment

Beach nourishment is the placement of large quantities of quality sand on the beach to advance the shoreline seaward. Costs are high, ranging from $1 million to $6 million per mile of beach nourished. Communities contemplating beach nourishment are understandably concerned over the longevity of their investment.

The ranges of performance estimates are large and disturbing in the face of a substantial investment. Orrin Pilkey, a geologist at Duke University, has stated: "Nourished beaches erode 10 times faster than natural beaches." He and his students have recently completed studies of more than 90 projects and disseminated the results widely, contending that none of the engineering parameters considered important in design can be correlated with project performance. Unfortunately, their correlation efforts have not recognized the geomorphic setting of the individual projects, nor the appropriate grouping of engineering parameters as an index of performance.

Sea Grant-sponsored research at the University of Florida has studied the principles of beach nourishment, accounting for the geomorphology of the area, the quality of the nourishment material, patterns of wave action, project length, and so on. Although the results are known for only a limited number of projects to date, the correlation of actual versus predicted performance is encouraging.

One important result is that if sand as coarse or coarser than that originally present on the beach is used in nourishment, then sand subsequently "lost" from the region is actually transported alongshore, benefitting the adjacent beaches, and certainly not lost to the system. An example is the Port Canaveral, Florida, beach nourishment project (1974) in which 2.4 million cubic yards were placed over 2.1 miles of beach immediately downdrift of the port entrance. Recent surveys indicate that we can still locate nearly every grain of sand placed, although it has been transported downdrift (southward). We are attempting to implement these findings by influencing accepted benefit/cost analysis procedures, to have them recognize and be more consistent with sediment transport processes.

An additional result of significance to a financing community is the amount of recreational beach resulting from placement of a particular volume of sand. It can be shown that the dry beach width depends critically on the size of the nourishment material vis-à-vis that of the native beach. Figure 4 presents four cases of the dry beach width resulting from placement of the same volume per unit length of beach (140 cubic yards per foot), but of progressively decreasing size. In case a (upper panel), the nourishment sand is coarser than the native sand, and results in the two profiles intersecting and an equilibrated beach advancement of 300 feet. In cases b, c, and d, the nourishing sand is progressively finer, and the resulting beach width decreases to case d in which the added sand is finer than the native and yields no dry beach width. All of the sand has moved offshore to an equilibrium form that "pinches out" at the shoreline, hardly the aspirations of a financing community! The only recourse when using sand of lesser quality than the native is to compensate with greater volumes.

Longshore Sediment Transport

In the period 1978–1982, the author participated in the Nearshore Sediment Transport Study (NSTS), the first of a succession of multi-university studies carried out under the aegis of Sea Grant. The general objective of this project was to develop an improved understanding of surf zone wave and sediment transport processes, primarily through several field programs.

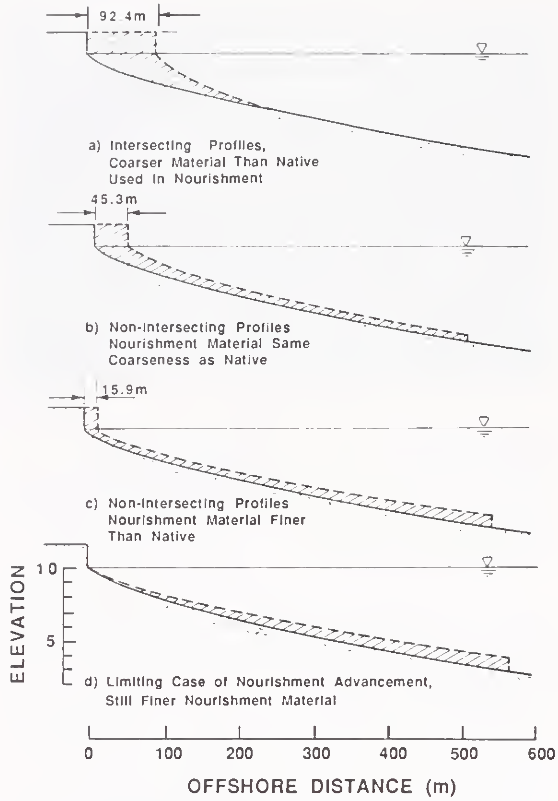

Figure 4. Effect of nourishment material size on width of resulting dry beach. Four examples of decreasing size.

The University of Florida's involvement in NSTS was limited to field programs relating wave characteristics to total longshore sediment transport. Two field sites (Santa Barbara, California, and Rudee Inlet, Virginia) were selected for their suitability as total sediment traps, and to provide a range of representative characteristics. Scripps Institution of Oceanography in California made wave measurements.

Comprehensive field surveys (Figure 5) documented sediment transport volumes, which were correlated with the appropriate wave characteristics. These correlations resulted in a transport rate dependency on sediment size, an important contribution to previous results. Additionally, the surveyed area west of the Santa Barbara breakwater was found to behave as a "leaky pocket beach" changing orientations with varying wave direction. This led to development of a method for extracting the distribution of sediment transport across the surf zone from such data.

Wave Breaking Across the Surf Zone

Waves, breaking across the surf zone, are recognized as the primary forcing function for cross-shore and longshore sediment transport. Also, waves represent a significant destructive agent during such events. Waves gather their energy from wind blowing over great distances, perhaps thousands of miles, yet this energy is dissipated in the relatively narrow surf zone by breaking. This breaking process generates turbulence, which mobilizes and redistributes sediments, transfers momentum from waves to the surf zone causing longshore currents, and an increase in mean water elevation called "wave set-up." The significance of the wave-breaking process requires accurate breaking models for realistic calculations of surf zone mechanics. The usually employed relationship is the so-called "spilling breaker" assumption, that within the surf zone, the breaking wave height is proportional to the local water depth.

Bill Dally, of Florida Institute of Technology, pursued this problem for several years. He has proposed a relationship that provides good agreement with the data, and includes unique significant features.

A Look at the Future

One of the striking features of modern-day colonization of the coastal zone is the rapidity with which it has taken place. Many of the buildings and facilities now located along the shoreline were constructed within the last two decades. This fast pace of development has not allowed exposure to infrequent storm events and the resulting modifications of development patterns.

Future modifications are likely to be implemented rather abruptly following severe storms, with the probability of significant decisions being required without an adequate technical base or background data. A severe storm causing major damage presents an opportunity to improve development patterns and principles.

Considering that a correct response exists, an incorrect choice could be inordinately expensive, in terms of continued inappropriate practices or of too conservative an allowance of private property usage. This setting provides a challenge for Sea Grant investigators to provide a proper framework for this decision-making process. Essential elements will include a quantitative understanding of the local background erosion rates, predictions of shoreline positions for various sea-level rise scenarios, costs to maintain the shoreline in a fixed position, and increased vulnerability of beaches to storms with a rising sea level. Such a capability would allow a deliberate decision-making process to be carried out in an open forum.

Future research agendas must include the dynamics of the surf zone and recognition of our poor understanding of this region. Although relevant knowledge has increased many fold in the last few decades, there is still much to be learned prior to development of rational design capabilities. Obvious questions include the rate

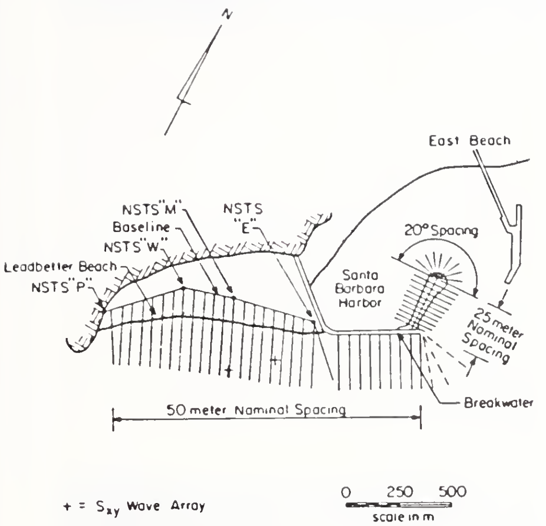

Figure 5. Santa Barbara survey plan and location of S_{xy} wave gages.

of longshore and cross-shore transport under given weather conditions, the relative roles of bed load and suspended load transport, the cause of rip currents, and the mechanics of longshore bar formation.

Substantial field programs will be required. The expense of such programs may appear inconsistent with past Sea Grant budgets; however, the magnitude of need for technical understanding of these problems should result in greater support, both directly in the Sea Grant budget, and indirectly through greater cost-sharing with the coastal states.

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The National Depository and Sea Grant Abstracts

Each of the 29 Sea Grant colleges and institutes has its own communications and publishing program. However, every document generated by the Sea Grant network is cataloged in the National Sea Grant Depository, located on the University of Rhode Island's Narragansett Bay Campus. These documents, now totaling more than 25,000, are available for loan. For further information, telephone (401) 792-6114.

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Some Sea Grant

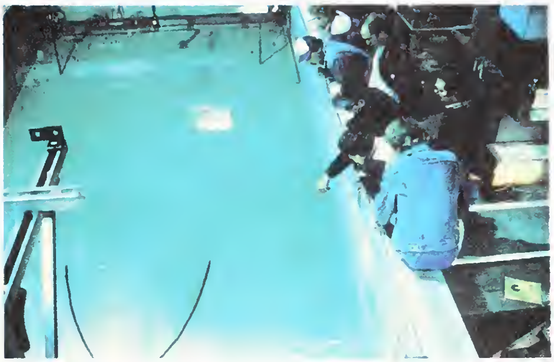
University Alaska Sea Grant sponsors survival suit demonstrations and tests for commercial fishermen such as this one held in Cordova, Alaska. (Photo by Peggy Parker)

Fishermen sometimes land fish other than the type they originally set out to catch and often discard these "trash" fish. California Sea Grant's Chris Dewees (right) and Bruce Wyatt test onboard processing of Pacific whiting, an underutilized species that is often an incidental catch in trawl fishing. (Photo courtesy of University of California Sea Grant)

A group from the University of Minnesota Sea Grant Extension Service inspects coastal erosion damage near Duluth. (Photo courtesy of the University of Minnesota Sea Grant Program)

This facility is typical of the modern soft-shell crab operations developed through advisory efforts stretching from New Jersey through Texas. Virginia Sea Grant's Mike Oesterling (right), works with soft-shell crab producer Randy Carr checking for crabs which are about to shed their shells. (Photo by Gloria Walters, Artworks, Inc.)

Advisory Activities



Trawl gear is designed and tested to maximize its efficiency in harvesting particular fish and in lowering fuel costs. Here, East Coast fishermen work at Rhode Island Sea Grant's trawl testing facility to evaluate a new trawl design. (Photo courtesy of University of Rhode Island Sea Grant)

Marine debris is a national problem. Here, volunteers clean up the productive Parguera mangrove habitat in an effort coordinated by Puerto Rico Sea Grant's Ruperto Chaparro. (Photo courtesy of University of Puerto Rico Sea Grant)

Sea Grant provides assistance to Gulf Coast fishermen on the use of TED'S (trawl efficiency devices) designed to exclude accidentally caught, endangered turtles while retaining actual shrimp catch. Gary Graham (front) of Texas Sea Grant explains operation of a new model TED to Capt. Hollis Forrester. (Photo by Laura Murray, Texas A&M Sea Grant)

Ports and harbors are an important link in U.S. international trade. Oregon Sea Grant's Fred Smith demonstrates an interactive video teaching module he developed to train port commissioners and port personnel in administration and management. (Photo by Tom Gentle, Oregon State University Sea Grant)

Triploid Oysters Ensure Year-round Supply

by Standish K. Allen, Jr.

For thousands of years, genetic engineering—in the form of selective breeding—has been the hallmark of agriculture. But even though humans have been farming fish for nearly as long as they have been tilling the earth, the use of genetic manipulation in aquaculture has only just begun. Less than 10 years ago, the first scientific report of artificially produced triploid* oysters appeared. Thanks to Sea Grant-funded research, from this beginning triploid oyster production has grown to represent 50 percent of the total oyster production of commercial hatcheries in the Pacific Northwest.

Two Sea Grant research programs, a continent apart, were the seeds that gave rise to this industry. The story begins in Maine, with the American oyster, *Crassostrea virginica*; moves to Washington and the Pacific oyster, *Crassostrea gigas*; and continues back on the East Coast, in the mid-Atlantic region, with the American oyster again. Research in Washington led to the first successful domestication of oysters on a commercial scale, which in turn could lead to a 35 to 50 percent increase in sales for Washington oystermen.

The Oyster Industry

In the Gulf coast and mid-Atlantic states, oystermen have largely depended on natural populations of oysters that spawn fairly regularly, but produce irregular recruitment to the fishery, which is harvested using dredges and tongs. Thus, the oyster is especially vulnerable to overfishing and the hazards of environmental fluctuations. In some areas of the country, the fishery also is vulnerable to pollution, degradation of the environment, and oyster diseases. For instance, a combination of these factors have contributed to the precipitous decline of the natural oyster fishery in the Chesapeake Bay region.

In the Northeast and the Northwest, however, there is another avenue to harvesting oysters. That avenue is aquaculture, or the rearing of marketable oysters by controlling the life cycle and culture conditions of each stage of the oyster's life. Oyster culture begins in a hatchery, with the induced spawning of sexually mature males and females, whose gametes subsequently unite and grow into embryos.

In hatchery culture tanks, embryos develop into free-swimming larvae and grow until they become competent to metamorphose into juvenile oysters, called spat. Competent larvae are usually set on material called "cultch"—normally consisting of shells—or they can be manipulated to set without cultch as individual spat.

The spat are "hardened" in the intertidal zone until they are ready for final maturation, or "grow-out". Depending on grow-out conditions—oysters can be reared on the bottom or in floating rafts—juveniles grow to market size in one-and-a-half to three years.

Controlling the life cycle through hatchery technology is essential for genetic approaches to oyster domestication. Such approaches may lead to disease resistance, faster growth, or triploidy.

Origin of the Concept

The idea for developing triploid oysters arose from an off-hand suggestion by a Sea Grant site review team evaluating a triploid fish project at the University of Maine, Orono.

Jon G. Stanley, then Assistant Leader of the Maine Cooperative Fishery Research Unit (MCFRU)—a joint university, state, and federal program—was conducting research on the management and culture of fish important to the region. When the author joined Stanley in 1976, he was developing a Sea Grant project to produce sterile landlocked Atlantic salmon for stocking in certain lakes in Maine. Stanley proposed a number of methods to produce sterile fish—one of them was by triploidy.

Most sexually reproducing animals have two sets of chromosomes, and so are called diploids (Figure 1, left). Meiosis is the process that reduces chromosome number by one-half, normally required to keep the chromosome number from doubling with each generation. It is a two-step process, whereby one diploid cell gives rise to four haploid cells, each with one set of chromosomes. One, or all four of these

* Triploid: having three times the *haploid* number of chromosomes. Egg and sperm cells normally are haploid. All other cells of animals normally have twice the haploid number of chromosomes, and are called *diploid*. Triploid animals normally are sterile.

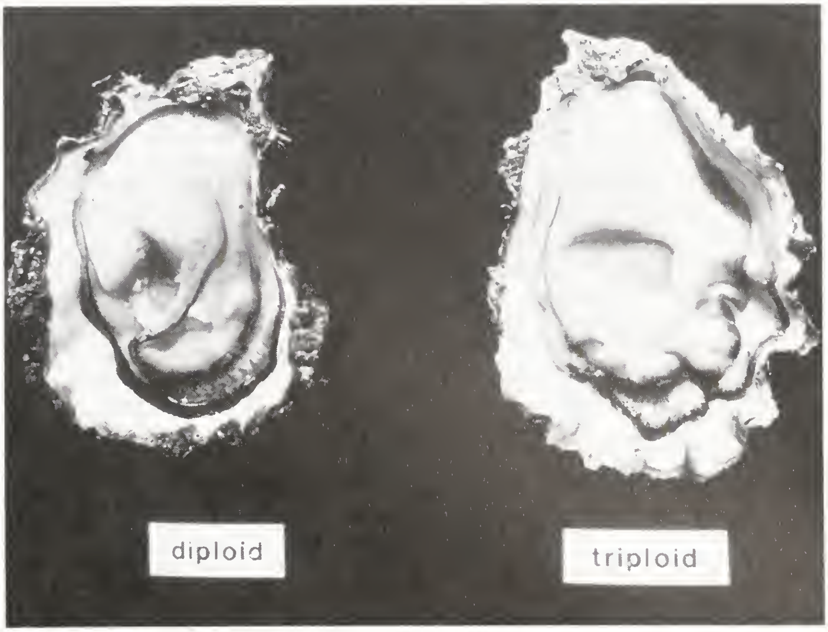


Figure 1. Diploid oysters can be distinguished from triploid oysters only during the spawning season, when diploids are sexually mature and triploids are not. The diploid on the left is ripe; much of the somatic tissue has been converted into gametes, giving the oyster milky white, turgid look. On the left, a triploid of the same age has the appearance of an oyster out of spawning season. Only a few pockets of milky white gonad are seen. (Photo by Jonathon Davis, University of Washington)

haploid cells may mature into functional egg or sperm cells, otherwise known as gametes.

Triploid animals have cells with three sets of chromosomes (Figure 1, right). Since normal meiosis involves an intricate pairing of the original two sets of chromosomes, the presence of a third set disrupts that pairing, and so triploids are usually sterile. The sterility can be the result of either a total lack of functional gametes, or the production of functional gametes in greatly reduced numbers.

Sterility in hatchery-reared animals has a number of advantages. For example, landlocked Atlantic salmon will produce gonadal—or gamete-producing—tissue, but certain populations of stocked fish are unable to spawn because of insufficient spawning habitat. Based on information already known about triploid amphibians, it was probable that triploid fish might be sterile. If sterile, fish might redirect energy ordinarily used for gamete production to body growth, thereby attaining larger sizes more quickly, and possibly living longer.

Today, a variety of techniques are available for producing triploid fish; in 1976, most techniques had yet to be tried. One technique showing promise back then was being developed using Atlantic salmon and rainbow trout. Terje Refstie of the Norwegian Agricultural Institute was treating fish eggs with the chemical, cytochalasin B, and reporting that polyploid embryos resulted. Sea Grant-funded research to produce sterile polyploids using cytochalasin B on landlocked Atlantic salmon was in full swing when a National Sea Grant site visit occurred. The site team—experts from other academic institutions—suggested redirecting the procedure on triploid fish to something "useful," such as oysters. Obviously one (or more) of the reviewers wanted more *sea* in the project.

But marine-based research presented a problem for Stanley, whose federal responsibilities for research within the MCFRU did not include marine species. He was not permitted to work on oysters unless there was a collaborator. Stanley enlisted the help of Herb Hidu of the University of Maine's Ira C. Darling Center. Hidu had been engaged in developing a prototype oyster hatchery to encourage a fledgling oyster culture industry centered around the Damariscotta River region in Maine. In the summer of 1978 a small project began to induce polyploidy in the American oyster using cytochalasin B.

The cytochalasins belong to a family of chemicals known for their effects on cell motility; they are called cytokinetic ("cyto-", cell; "-kinetic", movement) inhibitors. Inhibition of normal cell divisions in the developing fertilized egg is brought about because cytochalasin inhibits a subcellular assembly that plays a crucial role in cell division.

In fish and shellfish, meiosis is not fully completed in unfertilized eggs, which remain in an arrested stage until the process is restarted by fertilization. After fertilization, meiosis normally proceeds by eliminating three of the chromosome sets produced during the early stages of meiosis. These "extra" chromosome sets are eliminated when the egg packages them into small vesicles called polar bodies (Figure 2). Cytochalasin B inhibits the elimination of polar bodies, which is a special case of cell division. The set of chromosomes contained in the polar body is then reincorporated into the developing egg. Triploidy results from the union of the two

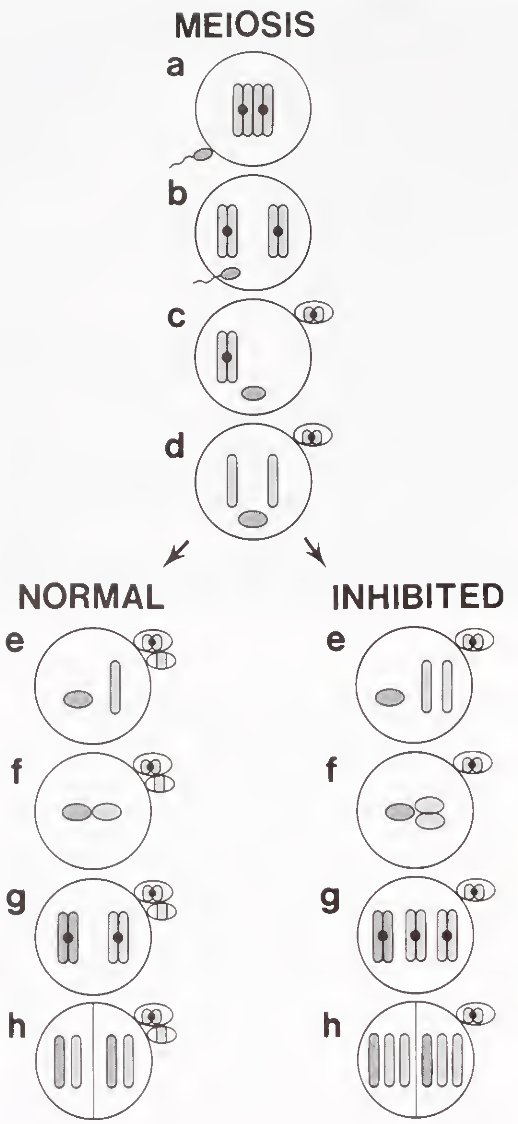


Figure 2. (a) Prior to meiosis, the two sets of chromsomes double to form two sets of duplicated chromsomes; duplicated chromsomes are held together by a centromere. (b), Fertilization activates the egg and meiosis resumes. (c), The first meiotic division results in the elimination of an entire duplicated set of chromsomes in the first polar body. (d), The second meiotic division divides the remaining chromsomes that were held together by the centromere. In the normal case, (e), one set is eliminated in the second polar body. (f), The remaining haploid set from the egg and that of the sperm unite in a process called syngamy which restores diploidy to the cell. (g), The diploid set of chromosomes duplicate. (h), Division gives rise to a diploid embryo. In the inhibited case, (e), an additional set of chromosomes fuses with those from the sperm and egg to form a single triploid cell (f). Subsequent duplications (g) and divisions (h) occur normally giving rise to an oyster with triploid cells.

sets of chromosomes from the egg, and the one set from the sperm.

Special Funding Pays Off

Early research at the Darling Center showed that cytochalasin B effectively induces triploidy in oyster eggs. In 1979, large numbers of eggs were treated with the chemical and fertilized, and the resulting embryos were reared to the juvenile stage. Diploids and triploids are indistinguishable on the basis of gross morphology, and the regular Sea Grant funding did not allow for more sophisticated techniques, so it was not possible to determine whether the treatment was successful or not.

The spat produced in 1979 were maintained into 1980, when special Sea Grant funds were approved for their microscopic examination. The result of that examination was the first report in the scientific literature of viable triploid bivalves that had been intentionally produced.

With both triploid fish and shellfish in hand, Stanley and Hidu hurriedly prepared a proposal to the National Science Foundation to study growth in these species. With NSF support, knowledge of triploid bivalves was expanded by producing triploid bay scallops, soft clams, and hard clams. One technique used in Maine proved to be crucial for the development of triploids on the Pacific coast in Washington.

The technique is flow cytometry, a method that draws a clear distinction between diploid and triploid oysters. Before flow cytometry, determining triploidy was a laborious task, requiring the examination of the chromosomes from each individual shellfish. Without flow cytometry, it is difficult to: 1) examine many oysters in a short time, 2) evaluate triploidy without killing the animal, and 3) determine ploidy when animals were dormant (because of the lack of cell divisions).

Flow cytometry is a technique developed for biomedical research to examine, among other things, the DNA content in cells. A fluorescent dye, which bonds specifically to nucleic acids, is added to a small number of cells. The cells take up the dye in direct proportion to their DNA content—the more DNA, the more dye is adsorbed. The cells are then illuminated with a light source that causes the dye to fluoresce. As the cells flow past a detector, the fluorescence is quantified and the data stored. Since triploids contain more chromosomes, they also contain more DNA (Figure 3). Flow cytometry analyses can be done rapidly, and require small amounts of tissue.

Triploids on the West Coast

Hidu and the author tried to introduce the idea of triploidy to the several hatcheries in Maine, but found little interest. First, the industry there was still small, hatcheries were struggling, and questions remained about the viability of the oyster culture industry as a whole. Second, gonadal development in the American oysters

cultured in Maine was not significantly detracting from their market value or growth patterns.

The Pacific Northwest, however, was fertile ground for developing the concept of triploid oysters. First, the oyster industry in the Pacific Northwest is firmly grounded in hatchery production of spat for commercial grow-out. The practice is so advanced that there is virtually no dependence on collection of natural spat, as there is in the mid-Atlantic and Gulf coasts. With hatchery-based technology, genetic manipulations can be accomplished, and such developments can have a large impact on the industry as a whole.

Second, the oyster growers in the Pacific Northwest are associated through the Pacific Coast Oyster Growers Association (PCOGA). This organization strives to improve the oyster industry in the Pacific Northwest by partially sponsoring projects that may benefit members.

Third, the Pacific oyster has characteristics that would make it an especially good species for inducing triploidy. Specifically, it is highly fertile, producing many more gametes than American oysters, and therefore provides many gametes for experimentation. Additionally, sexually mature Pacific oysters are inferior products for marketing in the summer. They become soft when reproductive tissues form throughout the body. The stores of energy-rich glycogen, which at other times of the year impart a sweet flavor to oysters, are converted during sexual maturation to less flavorful products. Triploids, if sterile, might be superior during this time since gametes would not form, maintaining both the texture and flavor of unripe oysters.

Pacific oysters are actually non-native to the Pacific Northwest, having been originally imported from Japan early in this century. (Native stocks were overfished.) As an exotic species, Pacific oysters are not well-adapted to some of the local growing areas. Waters are generally colder, and when oysters become sexually mature they may not spawn; nevertheless, they produce gametes, which diverts a great deal of energy from other physiological functions, such as growth and hardiness. In some grow-out areas mortality occurs during periods of sexual maturity; this is called "summer mortality". So producing sterile triploids might get around problems associated with sexual maturity and physiological stress.

Finally, Pacific oyster larvae are hardy and easily culturable. Because treating eggs with cytochalasin B can be a stressful interference, hardiness would be a factor predisposing Pacific oysters to such harsh manipulation.

From 1983 to 1986, at the University of Washington, in cooperation with the Coast Oyster Company and Wescott Bay Sea Farms, questions about the biology and production of triploid oysters—such as their sterility, and the feasibility of scaling-up to commercial levels of production—were addressed. It was possible that objections would be raised to using cytochalasin

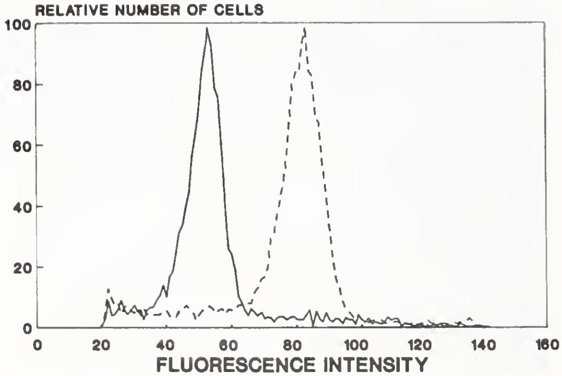


Figure 3. The solid line represents a frequency distribution histogram of stained cells from a diploid oyster; the dotted line, from a triploid. The fluorescence intensity of a triploid is approximately 1.5 times that of a diploid.

B on oyster eggs that eventually would be harvested for human consumption. One other method for inducing triploidy, by hydraulic pressure, was explored; but this method proved to be less effective than cytochalasin B treatments, however. The question of the safety of the treatments was settled when FDA ruled this use of cytochalasin B *de minimus*—that is, its use on oyster eggs engendered such a minimal risk in the adult oysters that regulation was not necessary.

Pacific Triploid Biology and Production

Research on triploid Pacific oysters revealed that production of triploids using cytochalasin B is quite predictable if several important variables are controlled. The most important of these is the temperature of the water at the time of fertilization and treatment, since development of the polar body is temperature-dependent.

Triploid adults are not completely sterile in that both males and females produce some gametes. Triploid females produce far fewer gametes than triploid males, that produce only about half of what diploid males produce (Figure 4). But absolute sterility is not essential for triploids to be valuable commercially. Reduced gamete production could be sufficient for marketing during the summer. Taste tests comparing diploids and triploids harvested during the reproductive season have demonstrated that triploids are overwhelmingly preferred in terms of taste and texture.

Triploids do not appear to grow faster than diploids in the first year. But in the second year triploids may grow faster, for one or two reasons. First, reproductive effort generally increases in the second year, so that the differences between fertile diploids and sterile triploids is accentuated at that time. The second reason may be due to the oyster's habit of changing their sex. They are

In Chesapeake Bay, two oystermen on a "skipjack" haul up an oyster dredge. (Photo by Michael W. Fincham, University of Maryland Sea Grant)

usually male first; then, some oysters in the population will become females. Since triploid females produce far fewer gametes than triploid males, a larger proportion of the population will be less reproductive.

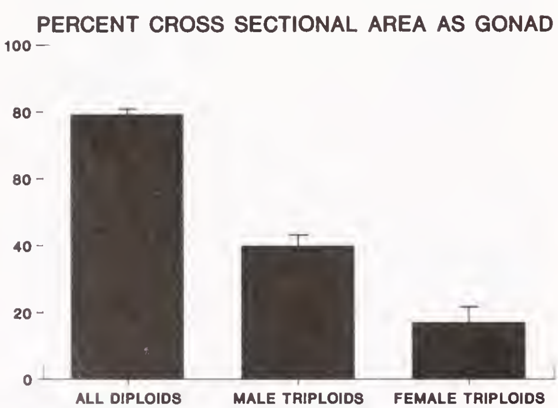
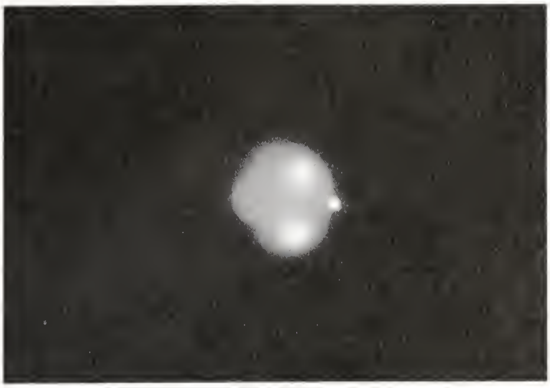
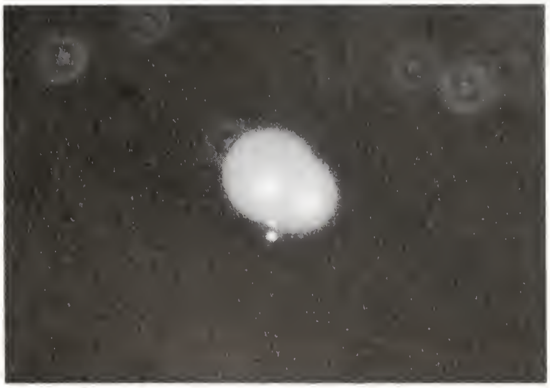


Figure 4. The gonad of oysters forms throughout the body. Gonad size is estimated by making histological sections from a standardized cross sectional cut. Using digital imaging, the proportion of the gonad that occupies the entire cross-sectional area can be measured. When fully ripe, the gonads of male and female Pacific oysters occupy approximately 80 percent of the standardized cross-section. Triploid male gonads are approximately half that and triploid females, half again. Bars represent standard errors.

Triploid oysters mean different things to different oyster growers. To companies that market oysters to gourmet restaurants for the half-shell trade, it means having a distinctive oyster of high quality during a time when the supply of such oysters has been limited. To larger firms that market vast quantities of shucked meats, it means eliminating the costly purchase of oysters from Asia during the summer.

Producing triploids means that there will be changes in the way hatcheries produce, grow, and market oysters over the next several years as more is learned of their biology. For instance, certain grow-out sites may be more or less suitable for producing triploids than others. Time to market may be more or less than is usual for diploids. Companies in the Pacific Northwest seem willing to make the effort for the triploid. In 1984, only a few thousand triploid larvae were produced at commercial hatcheries; in 1985, less than 1 million; by 1987, 2 to 3 billion, or about 10 percent of production; projected for 1988, about 12 billion triploid larvae will be produced, representing about 50 percent of total production.





The zygote at right is an untreated egg at the two-cell stage. At bottom is the first polar body and directly above it, adjacent to the egg, is the second. The diffuse fluorescent areas on the right and left of the egg are the nuclei of the two cells. They are diploid. The zygote at left has been treated with cytochalasin B to inhibit the extrusion of the second polar body. At right is the first polar body, but there is no second. The two nuclei on the top and bottom of the zygote contain three sets of chromosomes and so are triploid. Photos were taken with fluorescent illumination following fluorochrome staining. The zygotes are approximately 50 microns across. (Photos by Ken Cooper, Coast Oyster Company, WA)

Hindsight and Foresight

Twice, in two different states, Sea Grant has launched projects that had a larger scope than the original funds would have indicated. This fact illustrates one of the strengths of the Sea Grant concept, which is to encourage new approaches to problems of the marine environment.

Oyster hatchery technology is now attracting interest in areas where oyster harvests are still obtained from the fishery. Most of this interest derives from the serious decline of some of these fisheries, especially in the mid-Atlantic region. The work on the West Coast demonstrates that given control over larval production, it is possible to domesticate the wild oyster in much the same way that agriculture has done with crops. Work on triploid American oysters is resuming on the East Coast—some of it in conjunction with Sea Grant Extension and Advisory projects.

From the author's perspective, the idea of triploid oysters has progressed from a serendipitous suggestion to a major force in an industry. The awareness of the term, triploidy, has risen from obscurity. Before I left the West Coast in 1987, I was visiting a raw bar in downtown Seattle. I walked over to peruse the fare and asked the attendant if he had any triploid oysters, being accustomed to dumbfounded looks and quizzical expressions. Instead, the reply was "No sir, we haven't got any yet. However we expect to have some next year. But you don't need triploids this time of year [February] because oysters aren't ripe. You see the triploid is pretty much the same as the diploid now, but in the summer it's sterile and . . ." It was gratifying.

Standish K. Allen, Jr., is a Research Assistant Professor at Rutgers Shellfish Research Laboratory in Port Norris, New Jersey.

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Sea Grant Educators: Five Profiles

by David E. Smith

EDITOR'S NOTE: In 1983, at the request of the Council of Sea Grant Directors, the first survey analyzing the occupations of Sea Grant Program graduates indicated that nearly 7,000 students since 1966 had been trained in marine-related fields. First-employment information taken by graduates from 23 of 28 Sea Grant programs indicated that 40 percent entered the private sector, 32 percent the public sector, and 28 percent remained in academia. The people and experiences described in the following profiles are examples of careers attained through the Sea Grant education system.

When the Congressional architects drafted the National Sea Grant College and Program Act of 1966, they realized the importance to this nation of a workforce of "skilled manpower, including scientists, engineers and technicians" to understand, assess and manage this country's marine resources. To achieve this end, the legislation identified education, along with research and advisory efforts, as the underpinnings of the Sea Grant concept.

The education component of Sea Grant includes a broad range of activities that dovetail with research and advisory efforts. These activities involve supporting the research of graduate students, undergraduate course development and individual student projects. Teacher training, public education, technical and vocational education are also involved. The advisory services support many kinds of education as well—such as teaching marina operators better management skills, exposing seafood processors to new product quality techniques, and instilling confidence in teachers through new materials and information on the aquatic environment.

Above all, education is the mainstay of technology transfer between Sea Grant universities, and industry and government. For example, Sea Grant-supported graduate students participate each year in a variety of studies, from marine biotechnology to marine environment research, from projects in fisheries and aquaculture to research in marine engineering. Through this experience, they prepare themselves for the professional challenges that await them on graduation and become, in themselves, one of Sea Grant's primary technology transfer devices. In 1987 alone, Sea Grant supported approximately 450 graduate researchers throughout the country.

It is impossible to do justice here to all of Sea Grant's educational endeavors. Presented are the experiences of five individuals: together, however, they represent the breadth and depth of Sea Grant education.

Teaching the Teacher

Teaching about the Great Lakes as part of Sea Grant comes naturally to Rosanne Fortner, coordinator of the Ohio Sea Grant Education Program. "The characteristics of the Great Lakes are so similar to those of the oceans that the transition is easy. All our local ocean lacks is the salt and the echinoderms." She says.

Fortner knows the importance of effective teaching materials and techniques. After receiving her Bachelor's and Master's degrees, she taught for six years in the public schools of Virginia. According to Fortner: "I enjoyed my years teaching in public schools, and found the experience very satisfying. It's something I always wanted to do. But my science supervisor continually encouraged me to pursue my doctorate, to use my skills to become a teacher-leader." Eventually, she did return to graduate school and graduated with an E.D.D. in 1978.

The arena in which Fortner operates is not confined to the campus of Ohio State University. Elected 1988–89 president of the National Marine Educators Association, her experience, skills and knowledge will help guide this 1,000-member organization during the coming year. As Chairperson of the Education Task Force of the Great Lakes Commission, she spearheads the development and coordination of an environmental education strategy designed for teachers within the *entire* Great Lakes drainage

basin. The Ohio Sea Grant Education Program is serving as the model for this effort.

Fortner's commitment to coastal education transcends national boundaries as well. Within the next few months, she will be traveling to Moscow to take part in a conference comparing coastal science and policy problems of United States and the Soviet Union. These comparisons will involve case studies, and the exchange of natural and social science information.

Fortner, a specialist in environmental communication, and her colleagues, with their expertise in science education, take the story of the Great Lakes to teachers throughout the region. Beginning with the development of teaching materials, the Sea Grant educators produce a program that is comprehensive in scope, pedagogically sound, scientifically up-to-date, and reflective of Sea Grant's commitment to providing research findings to decision makers.

Teacher training takes several forms: one-day workshops, a full-term university course in marine and aquatic education, programs, and courses at OSU's field station on Lake Erie. A typical workshop includes lectures about major characteristics and issues of the lakes, the relationship between the Great Lakes and oceans, and hands-on sessions using the Oceanic Education Activities for Great Lakes Schools (OEAGLS) teaching guides.

OEAGLS are the basis for the excitement teachers find in an Ohio Sea Grant workshop. Where else can you:

- study weather patterns and bathymetry using the wreck of the *Edmund Fitzgerald* as a theme?
- calculate the erosion rate of a section of shoreline from aerial photos?
- examine real data to determine whether a fish advisory for PCBs is warranted?
- get to know your local fish through a card game and classification activity?
- role-play a Law of the Sea conference?

OEAGLS use the issues of the Great Lakes to teach the standard subject matter of middle school science and social studies. Teachers enjoy the infusion format, the ease of presentation, the low cost, and the accessibility of the Ohio Sea Grant staff for follow-up support as they need it. Though media documentaries have made the public aware of the characteristics and issues of the seas, nobody has done that for the Great Lakes. People do not look at a marine documentary and think: "Now, how does that apply to the Great Lakes?" Sea Grant gathers the science, especially the environmental quality information, and puts it into a form that teachers can use.

More importantly, for the whole marine education effort, the teacher education program in Ohio makes teachers aware of the facts about current issues affecting the Great Lakes.


Rosanne Fortner

Environmental success stories are few, and Lake Erie has one of the best. Once extremely polluted, Lake Erie today boasts significantly improved water quality thanks to the cooperation of local, state, and federal governments, the private sector, and the public. The Sea Grant Education Program in Ohio is a science-and-society program.

Inquiring Student/ Innovative Entrepreneur

Whether it is on a stage or on the mudflats, marine biologist Carter Newell has a winning way about him. Fiddler in the popular Maine Country Dance Orchestra by night, Newell is quality control biologist at the Great Eastern Mussel Farms (GEM) by day. He also finds time to work weekends at the Pemaquid Oyster Company, a cooperative American oyster farm of which he is president.

While studying aquaculture at the University of Maine's Darling Marine Center, Newell focused on the growth rates of the soft-shell clam. His Sea Grant-supported research has important implications for management, and will allow more accurate assessment of clam growth in a wide variety of environments. Newell received his Master's degree in oceanography in 1982.

Today, as biologist at GEM, Newell applies his background in aquaculture to produce quality mussels, helping to make Maine the biggest producer of mussels in the country. In 1985, Maine alone produced more than 2.9 million kilograms (meat weight) of mussels, and GEM

Carter Newell

produced more than 25 percent of Maine's total production.

According to Newell: "The training that I received through my Sea Grant research assistantship gave me the tools of the trade of a shellfish biologist, which I can now apply toward two important shellfish species in Maine—soft-shell clams and the blue mussel."

The training enabled Newell to assist GEM in applying new technology to optimize mussel production in Maine. Using flow cytometer particle counters, solid-state electromagnetic current meters, and hydro-acoustics, Newell has recently completed the feasibility study, or first phase, of a Small Business Innovation Research grant from the National Science Foundation to develop a mussel carrying-capacity model. This model will help Newell to understand the interactions of the environment with the mussels. During phase two, or the principal research phase of the grant, he will develop the model. In the third and final phase, Newell will use the results of the carrying-capacity model to alter planting and harvesting practices to increase mussel meat and volume yields. When this project is completed, GEM will be able to more effectively manage its mussel growing areas — the results of the feasibility study predict a 40 percent increase in meat yield from the same amount of seed, or young mussels.

Always looking for new ways to cooperate with other researchers in the region, Newell will rejoin forces with his former graduate adviser, Herbert Hidu, on a proposed Sea Grant project to investigate eelgrass-mussel interactions for their application to the aquaculture industry. Fifteen years ago, Hidu helped introduce aquaculture to the state through the University of Maine's first Sea Grant-funded project, which documented the faster growth and diminished predation of oysters at the Darling Marine Center.

Meanwhile, as Newell's research expertise has increased, his commitment to shellfish aquaculture also has expanded. The U.S. Department of Agriculture recently asked him to prepare the section on blue mussels for its National Aquaculture Development Plan, and he also is serving on the national task force to develop a Shellfish Seafood Inspection Program. In 1989, he will chair a special session on mussel culture for Aquaculture '89, a joint meeting of the National Shellfish Association and the World Aquaculture Society.

For Newell, who came out of graduate school looking for work in 1982, it is a particular pleasure to be able to create jobs for others now.

Reaching the Public

It is great to wake up every day and know that you have something to look forward to — to know that what you do is important. Jay Calkins knows this feeling.

Calkins is no stranger to Sea Grant. In 1983, while pursuing his doctoral degree in education, he received a Sea Grant Scholar Award from the University of Maine. As a Sea Grant Scholar, he produced a videotape for Maine's Sea Grant Advisory Program on groundfishing in the Gulf of Maine. Since graduating, Calkins has headed the marine education program for the University of Georgia Marine Extension Service where he is Associate Director.

With support from the Georgia Sea Grant College Program, the University of Georgia's Marine Extension Service has developed a strong, multifaceted education program at the Marine Resources Center on Skidaway Island. The program offers something for everyone. While kindergarten through grade 12, and college undergraduates are the major clientele for the Marine Resources Center, the program has expanded to include adult groups as well. According to Calkins, "Our whole purpose is to do more than transmit information. It is to spark interest in and maybe even commitment to an understanding of the ever-enduring relationship between man and the seas."

For example, Elderhostel programs for senior citizens draw people from all over the country for multidisciplinary instruction about the coastal environment, in general, and coastal Georgia in particular. These Elderhostelers spend a week learning about marine ecology, history, economics, fisheries, and prehistorical uses of the coast. One intensive Elderhostel is devoted entirely to coastal archaeology. Senior citizens spend a week excavating an important Indian village on campus. As many as 4,000 artifacts have been discovered from this site in a single week. Evaluations of these programs are

outstanding with many graduates returning for a second round. A two-year waiting list for some of these programs is testimony to their success. "Perhaps no other group that we teach has a more diverse background in education and experience than the Elderhostelers. They challenge us and inspire us, and they love us," says Calkins.

According to current trends, by the year 1990, 75 percent of the U.S. population will reside in states bordering on either ocean, or the Great Lakes. Important decisions will have to be made about the use and management of coastal resources. Development, beach erosion, the management of fisheries, use and abuse of salt marshes and wetlands, and the effects of pollution are all controversial issues that will be discussed for years to come. Since the public is ultimately responsible for decisions concerning the marine environment and marine resources, an aware public that is literate in marine affairs hopefully will make these decisions wisely. Calkins is doing his share to fuel the spread of wisdom.

Jay Calkins

Taking the Marine Option

What happens if you are an undergraduate majoring in history, but with a strong interest in marine issues? At the University of Hawaii, you might enroll in the Marine Option Program (MOP). This interdisciplinary marine education program provides academic and practical experience in marine studies that complements the more traditional degree programs.

Begun in 1971 at the University of Hawaii in Manoa with the support of the Sea Grant program, MOP opportunities now exist at all nine University of Hawaii campuses and are open to students in all fields.

Candidates in the MOP program may choose from two certificate options. To earn the Undergraduate Marine Certificate, students design a 15-credit curriculum of upper division courses in a specialty of biological, physical, or social marine science. Since marine specialties are not included as formal academic undergraduate majors, this certificate is analogous to an academic minor. For the Marine Option Program Certificate, candidates must complete 12 credits of marine related courses and, more importantly, a "hands-on" internship or research project.

Soon after the MOP program was initiated, Barbara J. Lee, who was raised in Hawaii and attending the University, joined the program. As a senior, she spent her internship helping to design and establish the University of Hawaii Blue-Water Marine Laboratory (BML), a seagoing science and seamanship program for high school students. Coincidentally, BML also was initiated with Sea Grant support. According to Lee, "My internship was largely spent going to sea with the infant Blue-Water Marine Laboratory, working with a variety of individuals and, in the end, knowing that I had contributed a large part to making a unique project possible. In reality, the late nights and days away at sea hurt my academics somewhat, but I do not regret it, considering what I gained. It was the first time I found an application for my major, biology, to which I could relate."

Barbara Lee

Clearly, the experiential education provided in MOP enhances and reinforces classroom learning. It allows the student to witness theory becoming reality at his/her own hand. The MOP experience gave Lee her first

opportunities as deckhand, galley cook, lab organizer, counselor, teacher, planner, mediator, and implementer. "When I began my MOP internship, I followed, I imitated, I assisted. By the time I graduated, I had come to face parts of myself I had never known before, began to find my individuality, confidence, and an intuitive kind of direction fortified by the experiences at sea," says Lee.

Lee has continued to follow this path. She has served as the coordinator of the MOP program as well as a high school science teacher. Today she works as a chemist at the Natural Energy Laboratory of Hawaii, an Ocean Thermal Energy Conversion (OTEC) research lab, and continues her volunteer efforts in aquaculture, ocean recreation, and public marine education.

Combining Policy with Science

Have you ever wondered how policy decisions in Washington are made? The National Sea Grant Fellowship program provides the opportunity for qualified graduate students to participate in this process, and this is where my personal Sea Grant story begins.

The Sea Grant Fellows Program/Dean John A. Knauss (see Knauss profile, page 75) Marine Policy Fellowships, originally called the Sea Grant Internship Program, was initiated in 1979. Through a national, competitive selection process, graduate students in marine policy and science are selected to work for one year in the legislative or executive branch of the U.S. government. The program is designed to be an extension of the student's formal educational training by allowing a firsthand look at how policy is formulated through legislation and regulation.

While an oceanography graduate student at Texas A&M University, I had become increasingly interested in the role science played in policy formation. So when the Fellowship opportunity arose, I jumped at it and spent 1981 working with the minority staff of the National Ocean Policy Study of the Senate Commerce, Science and Transportation Committee. With a new administration in the White House and a new majority party in the Senate, congressional staffs also were changing. For example, the former Senate majority staff had become the new minority staff and could no longer dictate the kinds of issues the committee would address.

I spent my year acting as a "generalist" with the responsibility of following many different issues: Ocean Thermal Energy Conversion (OTEC) legislative oversight, the evolution of the National Science Foundation's Ocean Margin Drilling Program, the U.S. involvement in and review of the Law of the Sea Convention, and the ever-present budget issues. My daily activities were almost as diverse as the issues for which I was responsible, and included:

- preparing background and briefing materials for the Senators on the committee;
- soliciting testimony, preparing questions, and staffing legislative and oversight hearings;

David Smith

- preparing floor statements for inclusion in the *Congressional Record* by the Senators;
- responding to constituent inquiries; and
- examining budget requests and assessing the effect of the budget requests on U.S. ocean policy.

This experience was exactly what I had wanted—intimate exposure to substantive ocean issues at a national level.

It was an exciting time—a time of professional and personal growth and a special learning experience. I left with an understanding of ocean issues, but more importantly, with an understanding of how the legislative process works. The creation, review, or demise of new science programs was no longer as confusing or mysterious. I also developed an appreciation for the kinds of scientific information that resource managers find useful in making management decisions—an appreciation I continue to draw upon in my current position as Assistant Director of the Virginia Sea Grant College Program.

Since 1979, more than 135 students have participated in the Fellowship program and they have gone on to careers in industry, business,

The University of Califoirnia's Sea Grant ocean education program provides workshops and field trips for residents and visitors to learn about the state's coastal marine life. (Photo by Carol A. Foote)

public service and academia. If asked whether the Fellowship was an insightful and a valuable experience, the Fellows I have known would all agree—no question about it.

The people and experiences described in these five profiles are not unusual within Sea Grant. Many other people from throughout the network could have been selected—teachers, researchers, or students dedicated to enhancing our understanding and use of marine resources.

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Acknowledgments

I express my sincere thanks to Rosanne Fortner, Carter Newell, Jay Calkins, and Barbara Lee for allowing me to use their experiences as a focus of this article. Kathleen Lignell, Sherwood Maynard, and Laura Wallace deserve special thanks for editorial assistance.

26th Underwater Photo Competition

The Underwater Photographic Society of Los Angeles is again sponsoring its International Underwater Photographic Competition. Entrants from around the world are invited to compete with prints and slides in five categories. The deadline for receipt of entries is October 15, 1988.

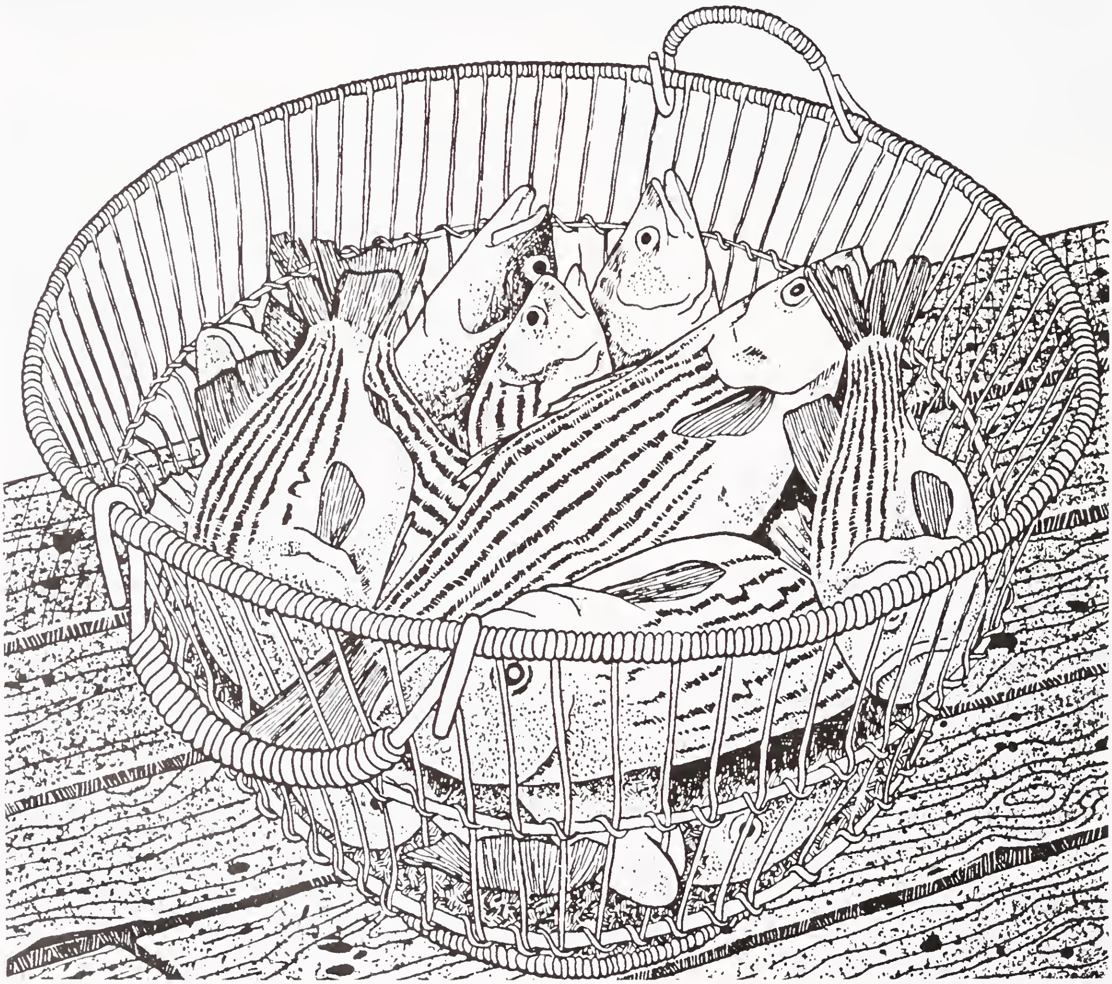
"Best of Show" will be awarded a plaque PLUS a round trip for two courtesy of CAYMAN AIRWAYS to Grand Cayman Island. There they will have a week's stay at Treasure Island Resort and 4 days diving for two, arranged courtesy of SEA SAFARIS and CAYMAN SAFARIS.

In each category, a plaque and $75 will be awarded to first place with a plaque and $25 for second place, and a medal for third place. For further information and competition rules, write to Lisa-ann Gershwin, Underwater Photographic Society, P.O. Box 2401, Culver City, CA 90231-2401, USA.

Farming Hybrid Striped Bass

The U.S. Department of Agriculture is studying the feasibility of using hybrid striped bass as an alternate crop for coastal and inland farmers. The hybrid striped bass industry has evolved during the 1980s to the point where there are a few fingerling producers in the country, and a few culturists producing food for the fish market. A growing number of researchers are also finding the culture characteristics of these fish particularly interesting. This interest is sparked in large part because natural populations of striped bass have continued to decline, particularly along the East Coast of the United States. Research on using hybrid striped bass as a food and recreational fish is focused in Sea Grant programs in North and South Carolina.

by Ronald G. Hodson, and Theodore I. J. Smith



Sperm being stripped from a striped bass onto eggs from a white bass. (Photo by John Brown)

Striped bass do well in a variety of environmental conditions. They can be reared in saltwater, brackish water, or fresh water. Indeed, ponds and reservoirs in a number of states, including North and South Carolina, have been stocked with hybrids for recreational fishing. However, there are impediments to the development of the industry. Fingerling production is uncertain because of dependency on wild broodstocks; there are questions about the size of the market and economies of production; and in some states legal restrictions limit the culture of striped and hybrid bass.

Hatchery Production

Hatchery production of eggs and larvae for the striped bass and hybrid aquaculture industry is generally based on the same technology that state and federal hatchery managers use. This technology is still dependent on collecting ripe broodstock from spawning grounds, transporting them to nearby hatcheries, and injecting the fish with human chorionic gonadotropin to induce ovulation.

Ovulation of a striped bass female usually occurs 25 to 40 hours after injection. The eggs are manually stripped from the female and fertilized with sperm from a white bass or striped bass male that has also been injected with hormone.

These eggs are incubated in jars at a rate of 100,000 to 250,000 eggs per jar until they hatch (except in the case of Chesapeake Bay stock, whose eggs must be incubated in tanks). Survival rate and hatching rate are dependent on the quality of eggs, but figures in the 60 to 80 percent range are considered good. The eggs hatch in 40 to 48 hours, depending upon water temperature (usually 16 to 21 degrees Celsius), and larvae are incubated in tanks for approximately five days, when they are ready to begin feeding. Then they should be placed in fertilized ponds or intensive culture systems.

Because of difficulties in obtaining and spawning ripe female striped bass, hybrid culturists in particular have begun examining the production of hybrids using white bass females and striped bass males. White bass females are more dependably obtained from the wild than striped bass, and they can be cultured and matured in outdoor facilities. The hatchery technology to produce this cross is similar to that used for striped bass. The females are injected with hormones and manually spawned. Sperm from the striped bass male is used to fertilize the eggs. Because white bass eggs are adhesive, the eggs must be treated with tannic acid before they are incubated in jars.

Development of the hatchery does not require extensive facilities. Site selection, however, is important because an abundance of high-quality fresh water is required for the hatchery. Ponds and tanks must be capable of holding domesticated broodstock from season to season.

There is unanimous agreement that lack of broodstock is a major constraint to the development of a striped bass and hybrid aquaculture industry. Problems still exist in the capture and spawning of wild-caught females, and laws and regulations pertaining to the collection of wild broodstock by private culturists are highly restrictive. Ultimately the long-term solution most beneficial to the industry would be to develop domesticated broodstock.

Fingerling Production

Many of the difficulties associated with striped

A five-year-old tank-reared striped bass female. (Photo by T. I. J. Smith)

bass and hybrid culture occur during the 45-day fingerling production period. Fingerlings are typically produced by stocking 5-day-old larvae in fertilized ponds at a rate of approximately 200,000 per acre (500,000 per hectare). Survival rates of 25 percent to 50 percent are considered acceptable. Successful production of fingerlings is dependent upon fertilization techniques aimed at the development of zooplankton populations, which provide food for the young fish. A combination of organic and inorganic fertilization, which generally begins two weeks prior to stocking, with supplemental fertilization two weeks after stocking, provides the best results when using larvae from crosses involving a striped bass female.

Larvae from white bass females are much smaller than those from striped bass and therefore require a smaller food item, usually rotifers, at first feeding. Pond fertilization techniques to induce and maintain rotifer populations for production of reciprocal fingerlings (white bass female × striped bass male) are less reliable. Survival of reciprocal larvae to the fingerling stage may vary from 0 to 80 percent, depending upon the rotifer populations in the ponds. Once striped bass and hybrids grow to a size of about 1 inch, they can be readily trained to accept prepared diets, and many culturists begin supplemental feeding in the ponds at this time.

Small fingerlings are normally harvested from the pond approximately 45 days after stocking, at which time they are 1½ to 2 inches. These fish may be stocked for fisheries management purposes or trained to feed and sold to culturists. Cannibalism is a serious problem during this stage, and the fish must be graded on a regular basis to prevent losses that can range from 30 to 50 percent.

The production of 6 to 8 inch fingerlings is accomplished by restocking small fingerlings into ponds during late June or July where they will remain until the end of the growing season. Stocking densities during this phase of production may be as high as 10,000 fingerlings per acre. Survival rates of 80 to 85 percent are considered good during this phase of production. These fish are usually fed a high protein trout or salmon diet at a rate of 30 to 1 percent of body weight per day, decreasing as the fish grows.

Striped bass and hybrids survive and grow well over a wide range of water quality variables. Advanced fingerlings of striped bass and hybrids generally will survive a temperature range of 4 to 34 degrees Celsius, with pond temperatures of 18 to 32 degrees being considered suitable for rearing. Maximum growth occurs at temperatures around 28 degrees Celsius.

Diseases and Treatments

Several disease problems appear to be routinely encountered in culture of striped bass and hybrids. However, because the industry is in an embryonic stage of development, much of the information on diseases has not published. The infectious agents that are commonly found, such as *Columnaris, Aeromonas, Vibrio,* and *Amyloodinium*, are not unique to striped bass and hybrids.

Salinity appears to be a significant barrier to the spread of some diseases, but many pathogens can affect fish in a wide range of salinities. There are no approved drugs for treating diseases in striped bass and hybrids being cultured for food except those that are exempted from licenses because they are generally regarded as safe (for example, salt).

Genetic Manipulation

Genetics in aquaculture is just beginning to be explored. Research on hybridization, introgressive hybridization, triploidy (see pp. 58–63), tetraploidy, gynogenesis, and gene insertion for a variety of species is being supported by the National Sea Grant Program and other research agencies. However, commercial application for most of these techniques is still in the future.

Processing and Marketing

The sale of cultured striped bass and hybrids to conventional seafood markets and restaurants is generally limited to one-and-a-half-pound and larger fish. A wide variety of processing techniques may be used, although fresh fish are often sold whole, gutted, or dressed, and on ice to assure high quality and extended shelf life. Special labeling may be required to distinguish cultured striped bass and hybrids from illegally obtained fish. Wholesalers generally prefer to receive fish iced and packed in-the-round.

Regulatory constraints have been imposed on the commercial capture and sale of striped bass in many states and these sometimes apply to the sale of cultured striped bass and hybrids.

Crustacean Shells May Aid Diseased Farm Crops

Shrimp and crab shells may one day provide the agriculture industry with an alternative to environmentally harmful pesticides and crop additives. In laboratory experiments, chitosan, a simple carbohydrate, stopped growth of disease-causing, or pathogenic, fungi and increased plants' resistance to fungi. These experiments were funded by the Washington State Sea Grant Program.

Chitosan is a derivative of the natural product, chitin. One of the most abundant organic compounds found in the sea, chitin is the major component of the hard shells of crustaceans. On land, chitin is found in the bodies of insects and the rigid cell walls of fungi. The cell walls of fungi also contain chitosan, itself.

When some pathogenic fungi are exposed experimentally to chitosan, the fungi stop growing, but they do not die. This is thought to be related to the fact that in unfavorable natural conditions, fungi seem to produce chitosan to induce a dormant state, to wait for more favorable conditions. Adding chitosan to a crop infected by fungi might therefore halt further damage.

Chitosan might also have a preventive effect. When chitosan is added experimentally to pea tissue before a known fungal pathogen of peas is introduced, the pea tissue becomes totally resistant to the pathogen. It is believed that chitosan activates the genetic machinery in the plant that aids in resistance, by "turning on" the genes coding for enzymes that digest the fungal cell wall.

The few agricultural applications of chitosan on a commercial scale have met with moderate success, depending on the cultivars involved and the prevailing climatic conditions. When applied to wheat cultivars susceptible to a certain stem-rotting disease, chitosan did not eradicate the disease nor its symptoms. Instead, chitosan extended the time the stem maintained the strength necessary to hold a full head of grain prior to harvest. The testing and use of chitosan continues, but its ultimate success is unclear.

The Alaska King Crab is one source of chitin for chitosan production. Left plate, the pea assay. Middle plate, powdered chitosan. Right plate, chitin.

Chitin is particularly attractive as a source of agricultural disease control because it is readily available and inexpensive. Nonedible portions of crab, containing unrecovered portions of crab meat, are often discarded into the sea near processing plants, causing locally severe pollution problems. Annually, 150,000 metric tons of chitin are available in these wastes. In recent years, research has uncovered uses for chitinous products, ranging from glue to surgical sutures. Further use for this waste by-product of the seafood industry would be welcomed.

—Lee A. Hadwiger
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Marketing of cultured striped bass and hybrids is restricted by some states along the East Coast because of two major problems:

- the inability or unwillingness of enforcement agencies to distinguish farm-raised hybrids from wild-caught striped bass; and
- laws prohibiting the sale of striped bass and hybrids because they are game fish.

Although many states allow the sale of cultured striped bass and hybrids, laws and regulations in some states will have to be changed to allow the sale of cultured fish on a year-round basis. Proper product identification is important in distinguishing cultured striped bass and hybrids from wild-caught striped bass.

Surveys of fresh fish wholesalers and distributors, and information from test marketing of cultured hybrid striped bass have shown that prices of $4.50 to $5 per pound for live cultured fish and $2 to $4 per pound for fish in-the-round are realistic.

Information Transfer

The technology for the culture of striped and hybrid bass has been established at the experimental level, but has not been

Net of striped bass × white bass fingerlings at 35 to 45 days. (Photo by Ron Hodson)

demonstrated conclusively at the commercial level. This technology is being transferred to culturists via Sea Grant Marine Advisory programs and, more recently, through the USDA Cooperative Extension Service.

The USDA has established a national aquaculture information center at the National Aquaculture Library in Beltsville, Maryland. The information center plays a major role in the acquisition and dissemination of literature and other aquaculture-related materials and is an important part of any technical transfer system. At this stage of development in the hybrid striped bass industry, there is a special need to transfer economic information that can be used by potential entrepreneurs in their decision-making process.

The National Sea Grant Program maintains a national depository for all literature produced through Sea Grant research at the Pell Library, Narragansett campus, University of Rhode Island. Striped bass and hybrid literature is available on loan from this facility.

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Acknowledgments

We appreciate the editorial assistance of Nancy Davis, UNC Sea Grant Communications.

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Researcher injects striped bass female with hormone to induce spawning. (Photo by John Brown)

Researcher examines a white bass female to see if it is ready for spawning. (Photo by John Brown)

Hybrids being harvested for market. (Photo by T. I. J. Smith)

profile

John Atkinson Knauss


Portrait by Dorothy Meinert

Founding Father

"There is no limit to what you can accomplish, if you are not willing to take credit for it." – Anonymous.

by T.M. Hawley

In the major marine science and management issues of the last 25 years, John A. Knauss has consistently played a

leading role, yet has just as consistently pointed to others when credit for the work was being divvied up. A soft-spoken man with an unusual sense of humor, the perennially bow-tied Knauss lives with his wife Lynne and one of their sons, William, in a warm, roomy house on the west shore of Narragansett Bay. Their other son, Karl no longer lives at home. Friends know the Knausses to be quiet but fun-loving people, little taken with the allure of power that John has come in contact with throughout his career. Rather then sending Christmas cards that lose their meaning in the crush of the holiday season, they send their holiday greetings to their friends in special cards, usually designed by Lynne, sometime during the year, but seldom near Christmas.

Sea Grant is what it is today, because of Knauss' vision and action since the idea was first mentioned. U.S. coastal-zone management today is likewise largely a product of his long view and hard work. Despite roadblocks set up by the more powerful, oceanographers worldwide are as free as they are to do research within exclusive economic zones thanks to his tenacious work. For more than a quarter-century, while influencing national and international marine policy, he nurtured the University of Rhode Island Graduate School of Oceanography (GSO) from its modest beginnings, to its present, globally respected, position. This much is public record, and was celebrated when Knauss retired as dean of the GSO last year. Francis Horn, the man who hired him as dean, said that Knauss' appointment was the "most important" he made as president of the University of Rhode Island. From talking to Knauss himself, though, you would think that he was just one of many who did a little bit here and a little bit there to help good ideas move along.

Knauss, with a B.S. in meteorology from Massachusetts Institute of Technology, an M.S. in physics from the University of Michigan, and a bow tie at his collar, got his start in oceanography back in 1947 at the Naval Electronics Laboratory. He stayed in San Diego with the Navy long enough to become a physical oceanographer at the Office of Naval Research, before completing his formal oceanographic training at the Scripps Institution of Oceanography. At Scripps, for his Ph.D. research, he made the first full-scale measurements of the then-newly discovered Cromwell, or Pacific Equatorial Undercurrent. Although the current was discovered in 1952, Knauss' work demonstrated the importance of the Cromwell by showing it to be a narrow, coherent feature of the central and eastern Pacific.

In the 1950s, Scripps was the home port for what was to become a generation of leaders in oceanography. Knauss got his Ph.D. from Scripps in 1959, and paid tribute to those heady days and memorable personalities by writing a comedy for the stage, complete with original poetry set to music. Reviews of the single performance cited Knauss' depiction of lonesome wives as especially witty. He stayed on as a researcher at Scripps until 1962, when then-President of the University of Rhode Island (URI), Francis Horn, asked him to become the first dean of the Graduate School of Oceanography. While his work at Scripps remains theoretically topical today, it is in Rhode Island where Knauss' most important contributions to oceanography begin.

The Young Dean

At the age of 36, he started to build an oceanographic institution that, at the time he arrived, was described as: "Just a garage and a few people, halfway between Woods Hole and Lamont-Doherty—two of the major oceanographic centers in the world—in the smallest state going, with an awful budget, and on top of it, it was not the even the key university in the state." When he retired as dean in 1987, the GSO had 40 faculty, and was bringing in more than $15 million a year in federal research funds. More importantly though, the GSO is now universally recognized as being in the top tier of oceanographic institutions. But Knauss deflects credit with a shield he never drops. He

"People saw this entire frontier out there that the U.S. was not organized to play a leadership role in."

points to the faculty as being responsible for research funds. On receiving accolades for being the one who saw—and then realized—the potential of the GSO, he says simply that he considers himself lucky that in 1961 few of his more senior colleagues appeared interested in building an oceanographic program at Rhode Island.

In the early to mid 1960s, Knauss says: "Oceanography became quite a popular field, which captured the imagination of a lot of people, including those in politics. Political people saw this entire frontier out there that the U.S. was not properly organized to play a leadership role in." He knew that, considering the neighborhood he was moving into at Rhode Island and the GSO, at least the trappings of a major oceanographic institution were necessary. So before he left Scripps, he spent $500 through "educational surplus" for a 180-foot, 1,000 ton "research vessel." The ship was actually a mothballed army "floating machine shop," as a colleague at URI puts it. One of her sister ships, the *Pueblo*, became well known, if unhappily so, later in the decade when she was captured in North Korean waters. The URI ship was named the *Trident,* and Knauss nearly spent the balance of his first

year's budget in getting it towed to San Diego, where it was outfitted under the direction of his Captain/Marine Superintendent (whom he had hired away from Scripps) and his secretary (who had her office in her own home). "It was a good vessel. It served us well over the years." Knauss says.

It was important during those early years to make the greatest possible use of the ship, so Knauss made sure that prospective faculty members would happily spend large amounts of time at sea. He saw that the growing output of GSO researchers, if connected properly to the national fascination with oceanography, could eventually establish his institution as an equal among the East Coast heavyweights. He knew that things were going to be happening in U.S. oceanography, and his strong position at what was then a growing institution gave him the flexibility to take advantage of the new research and policy opportunities that were opening up.

Aside from the time Knauss spent on research cruises, his time at sea has been concentrated around the activities of the Saunderstown (Rhode Island) Yacht Club, where he has been a longtime member. He does not fit the stereotype of a 12-meter racing Commodore, though. Knauss has never owned a boat larger than the 14-foot Javelin, named *Condor*, that he raced 15 to 20 years ago. But a fellow club member recalls that Knauss' older son Karl, now a Navy helicopter pilot, was a far more successful skipper than his father ever was. More often, Knauss piloted a 12-foot, 4-inch Beetle Cat. With a beam of six feet, these boats are celebrated for their stability, not their speed; and in one of the less dignified moments of his sailing career, Knauss explored the limits of his Beetle's stability, capsized her, and won the first "Most Unseamanlike Award" ever given by the Saunderstown Yacht Club. He has since retired the Beetle Cat, and now takes his exercise on the tennis court.

Organizer of Sea Grant

When the origin of Sea Grant is celebrated, the spotlight zooms to people such as Athelstan Spilhaus, Rep. Paul Rodgers of Florida, and Sen. Claiborne Pell of Rhode Island, with Spilhaus as the originator of the concept and coiner of the phrase, and Rodgers and Pell as the congressional shepherds of the funding legislation. But John Knauss is the one who organized the symposium in October of 1965 that first got the key people together. It was only after this symposium that anyone had a definite idea of what a Sea Grant Program was to be, or how it was supposed to function. Characteristically, Knauss fends off acclamations of credit, either in the direction of his then boss, Francis Horn, who asked him to see what it would take to get the Sea Grant concept off the ground in the state; or he might say that the time was simply ripe for Sea Grant, and anyone might have filled the role he played. The fact remains, however, that John Knauss played the role, and it is to him that its curtain calls belong.

In September, 1963, Spilhaus gave a speech to the American Fisheries Society, invoking the term "Sea Grant College" for the first time. It was a time of increasing national support for oceanography, but what was lacking was a unified vision of where U.S. oceanographic research and engineering was going. Knauss remembers that each aerospace program had its own submarine development plan, for instance. After Spilhaus's famous speech, oceanographic administrators, and legislators from coastal states wrote letters and discussed among themselves how to realize the Sea Grant concept. Knauss filled the organizational void by calling two symposia at Rhode Island, in October, 1965—the "Sea Grant College Conference" for the 28th and morning of the 29th in Newport, and a meeting of the National Academy of Sciences Committee on Oceanography (NASCO) for the afternoon of the 29th and the 30th at the University. By getting the key people in the same place at the same time, the moment was seized, and the concept took a big step toward realization.

An important meeting took place several months before the symposium, however; Knauss was working in the lab on a Saturday morning, and the new senator from Rhode Island, Claiborne Pell, happened to wander through with his young son in tow. Knauss recalls that as he, the new dean, chatted with the new senator, "I talked to him a little bit about Sea Grant, and he got quite excited about it, right from the very start. As a matter of fact, by the time the conference was called, he had introduced legislation."

He consistently knows where the good ideas are, and who their prominent spokespeople will be.

Because of his central role in organizing Sea Grant, during the mid 1960s Knauss began to navigate the straits of the high-level U.S. research bureaucracy. He chaired the National Committee for Sea Grant Colleges, formed following the October meeting; served as president of the Ocean Sciences Section, American Geophysical Union from 1965 to 1967; and chaired the National Advisory Committee of Ocean and Atmosphere (NACOA). Travelling in this society enabled Knauss to make the connections necessary to benefit the Sea Grant program. He has been cited as the one who: "helped get a consensus, get people together—providing the catalyst to keep the idea moving." These connections also benefitted

the University of Rhode Island, and helped him to play an increasingly influential role in national and international marine policy.

Despite the proximity to the halls of power that Knauss has experienced during his career, he has never been taken in by those too taken in with themselves, and his slightly off-beat sense of humor often finds its mark at the expense of ceremonies created for self-aggrandizement. In 1959, with Art Maxwell and Gordon Lill, he founded the "Albatross Award" of the American Miscellaneous Society, an amorphous organization, which even its members (there is no membership list) find difficult to describe. The award is an enormous taxidermied albatross in a large wooden cage. Among past recipients is Paul Scully-Powers, the first oceanographer in space, who got the Albatross for proving that one can practice oceanography while being absent from Earth. More recently, Scripps oceanographer Joe Reid was selected for his contention that numerical models of oceanographic phenomena should have a basis in reality.

He has always been one who is happy to have others, such as Spilhaus or Pell, make the big public appearances and give the visionary speeches. But at the same time, he has always been the one to do the leg work necessary for the realization of important projects that benefit the oceanographic community. When people talk of his accomplishments, what you hear is that he consistently knows where the good ideas are, and who their prominent spokespeople will be; you hear about how his satisfaction lies in seeing the good ideas come to life, not in being recognized as the one who was responsible for the outcome.

The Stratton Commission

In 1967, the profusion of oceanographic activity in the U.S. that had been growing for a decade came to a focus in a specially appointed Presidential commission officially known as the "Commission on Marine Science, Engineering and Resources," but is popularly known through the name of its chairman, as the "Stratton Commission." Knauss was primarily responsible for its recommendations on coastal-zone management.

"Leon Jaworski, the lawyer, played a big role in developing the 1972 Coastal Zone Management Act."

At the time of the Stratton Commission, responsibility for U.S. ocean activities was housed in six departments, four independent agencies, and 17 agencies and subagencies within other departments. Addressing this uncoordinated approach to the oceans, the two most far-reaching recommendations of the commission were the establishment of: 1) an independent agency for the oceans and the atmosphere; and 2) a public advisory body to the President and Congress on oceans and the atmosphere. The agency that was eventually established—not independent, but rather as a part of the Commerce Department—was the National Oceanic and Atmospheric Administration (NOAA); and the advisory body became manifest as NACOA.

Knauss remembers that, in developing a plan for national action on the coastal zone, a central question was where the authority was to reside. Local governments are particularly susceptible to well-financed pressure for development; but at the local level, federal pressure for almost anything is not often well-received. The coastal zone itself is subject to a spectrum of pressures—the best-planned system for natural preservation can be crushed by out-of-town development money, and the most profitable recreation complex could be smashed by a hurricane.

"We could not assume that the coastal zone would take care of itself, based on town zoning. On the other hand, we didn't think that 'national zoning' was the way to go either; because that's too far removed from the people. So our concept of a state organization that would have overall responsibility for coastal-zone management was our compromise. One of the members of our coastal-zone panel was Leon Jaworski, who is best-known for his work some years later, as the man who prosecuted Richard Nixon. Leon was useful, he played a very big role in our discussions. When we came down to the relative roles of the town, state, and federal governments, as a good lawyer, he asked some very difficult questions, which we had to resolve before making our final recommendations to the commission."

Summing up his work on the Stratton Commission, Knauss simply says: "I learned a lot."

Knauss' recommendations were substantially incorporated into the 1972 Coastal Zone Management Act. A key point of the act was its provision for matching funds to states developing and implementing management programs that achieved a balance of cultural, ecological, aesthetic, and economic values. It also mandated that federal activities in the coastal zone be consistent with the states' management plans. Federal funding assistance for the acquisition, development, and operation of estuarine sanctuaries by coastal states was another important provision of the act.

The Nixon administration dragged its feet when it came to funding the act, until congress pressured it

into doing so in 1974. Even so, the first management plan—the state of Washington's—was not approved until 1976. Despite the obstacles to the realization of Knauss' vision for management of the coastal zone by the Nixon and Reagan administrations, without the strength of that vision our coasts would no doubt be less attractive places than they are today. It took long days of hard work to frame the vision contained in the commission's report, and continued work in helping the substance of the report to become enacted into law. When summing up his work on the Stratton Commission, Knauss simply says: "I learned a lot."

Law of the Sea Conference

Much of what Knauss learned during the time of the Stratton Commission was put into service during the Law of the Sea Conference. Beginning with some of the preparatory meetings in 1970, he was a member of the State Department-appointed Public Advisory Committee. Soon he organized some of the other members of that committee, including the late Paul Fye, former WHOI Director, into what was called the Freedom of Science Task Group (FOSTG).

"We took it upon ourselves to represent the interests of the marine scientists in the Law of the Sea." With FOSTG, and later with the National Research Council's Ocean Policy Committee, Knauss continued to "play a role, trying to influence, as far as one could, the Law of the Sea, to give the best deal possible for marine scientists. We were able to convince the U.S. government that it was an important issue, particularly when Elliot Richardson became head of the U.S. delegation."

Unfortunately, the strong support that the Soviet Union had given for freedom of scientific research in exclusive economic zones evaporated shortly after the U.S. jumped the gun on the Law of the Sea, by declaring a 200-mile fishery zone in 1976, several years before the Law of the Sea Conference concluded. Knauss believes that the declaration by the U.S. and withdrawal of support by the Soviet Union "were not unrelated."

"He's always been very constructive. He always sees the positive side of things."

The interests of the developing world, and coastal states in particular, prevailed in the Law of the Sea Treaty, as Knauss sees it. He also found it more difficult than he expected to gain the support of the European science community. "For many it was a political issue in which they did not wish to be involved."

"It is much more difficult to do marine science now than it was before the Law of the Sea Treaty, because of the coastal states having almost complete jurisdiction over marine scientific research in their 200-mile zones. What we fought for was to try to minimize the restrictions on marine scientific research in these zones. We won a few battles, but we lost the war."

Retirement, et cetera

After 25 years as dean of the GSO, Knauss retired in June, 1987. He has since spent about nine months at the Centre for Environmental Technology, Renewable Resources Assessment Group, of Imperial College in London. He believes that in the years ahead, the most interesting areas in marine policy will be those dealing with global environmental effects such as the ozone hole, sea level rise, and transboundary and open ocean pollution. He has now returned to a teaching and research position at the University of Rhode Island, where he is using his years of experience in marine policy, and his recent experience in England, to teach and work on those issues he sees coming to the fore in international law. He is also planning to return again to physical oceanography, a career that has been on hold for much of the last 25 years.

Knauss' habit of redirecting kudos away from himself, and his proclivity for bow ties, were spoofed during the circuit of roasts and parties that ensued following the announcement of his retirement as dean. The faculty celebrated him as the "King of the Narrangansett Bay Campus; and one of his bow ties is now preserved as a rare form of Narrangansett Bay marine life, on the shelves of the biological museum at the University of Rhode Island's Pell Library.

Among all the other things that just sort of happened in Knauss' wake was a change in the self-image of Rhode Island. Years ago, the state pointed to its extreme position in the listing of states by size, by calling itself "Little Rhody." But by the time he retired from his role as the premier marine consciousness-raiser in the state, Rhode Island had thrown away its concern with its low square miles of land total, and instead identified itself as the "Ocean State."

If you are ever fortunate enough to be a house guest of John Knauss, and take the wrong road toward Narragansett Bay from Route 1A, you might just find yourself looking at a street sign that reads: DEAN KNAUSS DR. It is not a grand avenue or a superhighway; it is a nice, scenic road by the bay. And it is appropriate that way. One of the things that I was told by a long-time colleague and friend of John Knauss was: "He's always been very constructive. He always sees the positive side of things. The parties they give for him are very touching. He's the type of guy you'd like living on your street."

T. M. Hawley is the Assistant Editor of Oceanus, *published by the Woods Hole Oceanographic Institution.*

letters

To the Editor:

We read, with extreme interest, the 1987 winter issue of *Oceanus*, which presented an overall view of marine science in the Caribbean. These articles are very much appreciated, since they provide key information regarding institutions, existing data, laws of the sea, etc., to marine scientists in the region, and all other scientists willing to become involved in the study of the area. The lack of information has long been a handicap in third world countries, and all efforts in this direction must be reinforced.

The article entitled "Petroleum Pollution in the Caribbean" was of special significance for us at Intevep (R&D Center of the Venezuelan Oil Industry), since it provides valuable overall data about the fate of petroleum spills in the region. Further, it provides information on the international efforts attempting to assess the degree of the local and regional oil pollution problems. In this sense we feel it is important to express the effort carried on by Intevep towards the physical oceanographic characterization of the Venezuelan continental shelf during the last decade. So far, Intevep has carried on the largest Venezuelan effort in this field (unfortunately ignored by A. Meriwether Wilson's article on "Caribbean Marine Resources: A Report on Economic Opportunities," evidently due to the lack of scientific communication mentioned above). Briefly, this has consisted in the installation, maintenance, and analysis of oceanographic and meteorological data from 27 stations in the Venezuelan continental shelf, which have served as input data for numerical modeling of possible spill trajectories, and has helped in trying to minimize the environmental impact from sea-related activities of the oil industry.

Further efforts for local and regional programs dealing with the assessment and control of Caribbean pollution should be encouraged by national governments and international agencies. Articles like those in this volume of *Oceanus* represent a major contribution in this determination.

José L. Pelegrí
Research Oceanographer, Intevep
Carlos Villoria
Research Oceanographer, Intevep
Venezuela

Letter Writers

The editor welcomes letters that comment on articles in this issue or that discuss other matters of importance to the marine community.

Early responses to articles have the best chance of being published. Please be concise and have your letter double-spaced for easier reading and editing.

To the Editor:

I am writing, I agree, a bit late, but it has only been recently that I finished reading the articles in the summer 1987 copy which was devoted to the Galápagos. It was excellent, indeed very informative, had useful information, and was another much needed boost to the Galápagos morale. Except for one thing: your article "Galápagos Tales" was, well shall we say quite honestly and openly, rubbish. I can say this with authority, as I was born on the island, and have lived there all my life, apart from a brief period in England. I have experienced the Galápagos from before the park controls and tourism up to our present day, not a long period for a lot to take place. At present, I am a Galápagos Park guide, professional photographer, and diver in the islands, and my concern, both personally and publicly, is great. That is why I feel that your article is so poor. It is negative, very slack in useful information and fact, and quite honestly degrading to the people who try to do their best. Above all, it will give someone who is ignorant of the Galápagos a very poor opinion.

I really cannot understand the article's purpose. Its lack of foundation means that you have obviously forgotten that this is South America, and things—although not always correct—are done differently. So my advice is to accept, to help to improve, and make the best of it, or, I'm sorry to say, just forget it!! I certainly agree that there is need for improvement, but of the many here who have read it, it causes nothing more than the very reaction you are receiving in this letter. I'll be frank! "We don't need it."

Standards are different in different places. Accept, help out, encourage, and be patient or not, but don't condemn a different way of life just because it doesn't match up to your expectations.

The Galápagos needs everything it can get, and it is in fact being influenced by too many people for the wrong reasons. So I ask please, paint a more positive picture, that at least mentions the negative aspects in a positive way, and carefully explains the problems. We need help, but not this, not yet.

In the future, I would be more than willing to contribute a realistic picture of these unique islands for your magazine. I hope to hear from you. Please don't take what I have said personally; it's just that as a resident I see many ideas, both positive and negative, of the situation here. To help out is a major task. Thanks!!

Daniel Fitter Angermeyer
Puerto Ayora, Santa Cruz
Galápagos, Ecuador

EDITOR'S REPLY: I can only plead that you have misinterpreted my intent and words in "Galápagos Tales." It was written as a light, humorous piece to offset some of the serious science articles in the issue. I myself, in the role of visitor tourist, was an object of this humor. All the events were factual, but chosen and depicted in such a way as to give the reader the flavor of *my* experience in the islands—islands which I have a fond memory of, a high regard for, and which I hope to return to one day. Incidentally, I speak Spanish and have spent five years living and working in Latin America.

Paul R. Ryan
Editor, *Oceanus*

To the Editor:

I have just read the excellent *Oceanus* issue on the Antarctic, Volume 31, Number 2. I thought you might be interested in the origin of the map on page 2 of that issue.

I devised this map in 1942. It was published in the *Geographical Review* of that year. It is contribution #318 from the Woods Hole Oceanographic Institution.

Athelstan Spilhaus
Middlebury, Virginia

To the Editor:

Thank you for your copy of the Caribbean Marine Science issue of *Oceanus* Vol. 30, No. 4. It has been enjoyable reading from first to last page.

Luis J. Urosa M., Director
Instituto Oceanografico de Venezuela
Universidad de Oriente
Nucleo de Sucre

ANNOUNCEMENT

The Decade of North American Geology (DNAG) Project was initiated as part of a centennial celebration of the Geological Society of America. Its goal was to prepare a comprehensive synthesis of current information about the geology and geophysics of North America and adjacent oceans areas. Participants included more than 500 geologists and geophysicists from more than 100 universities, dozens of provincial and state geological surveys, government agencies, and exploration companies or consulting firms.

Much of the digital, geophysical data for this project are being made available through the National Geophysical Data Center. These data include:

- Gravity
- Magnetics
- Earthquake Seismicity

It is anticipated that other data will become available as additional maps are published.

For information, please contact:

National Geophysical Data Center
NOAA (E/GC1), Dept. 629
325 Broadway
Boulder, Colorado 80303
(303) 497-6128

International Conference on TIDAL HYDRODYNAMICS

November 15–18, 1988
National Bureau of Standards
Gaithersburg, Maryland, USA

The **International Conference On Tidal Hydrodynamics** will be held **November 15–18, 1988** at the National Bureau of Standards in Gaithersburg, Maryland, 15 miles north of Washington, D.C., USA. The conference is sponsored by the Office of Oceanography and Marine Assessment in the National Ocean Service, NOAA and the Physical Oceanography Committee of the Marine Technology Society.

The program for this 3½-day conference consists of more than 70 papers from eleven countries, grouped into six sessions: 1) Tidal Analysis and Prediction Techniques; 2) Tidal Hydrodynamic Phenomena and Modeling; 3) Nonlinear Tidal Interactions In Shallow Water; 4) Internal Tides and Baroclinic Effects; 5) New Approaches To Tidal Data Acquisition; and 6) Tidal Applications, Products and Services. The program has been organized to be comprehensive and to cover all state-of-the-art developments, including tidal detection from satellites, nonlinear tidal interaction, and global modeling. One objective of the conference is to produce a refereed volume to be published by a leading book publisher, that can serve as a reference on the tides.

The registration fee is $275. Early registration is recommended because space will be limited. The fee includes a post-conference refereed published volume. For further information, contact:

Dr. Bruce Parker, Chairman Steering Committee
International Conference on Tidal Hydrodynamics
N/OMA13, Room 414
National Ocean Service, NOAA
6001 Executive Blvd.
Rockville, MD 20852

Information can also be obtained via Omnet Telemail (B. PARKER/OMNET) or Fax (301-443-8539), or by calling (301) 443-8768 or (301) 443-8060.

book reviews

***Georges Bank,* Richard H. Backus and Donald W. Bourne, eds. 1987. The MIT Press, Cambridge, Massachusetts. 592 pp. + x and a bathymetric chart. $225.00.**

Georges Bank, that large club-shaped extension of the continental shelf off Cape Cod, is one of the world's most important fishing grounds, a *cause célèbre* of environmentalists, and a bone of contention between the United States and Canada. Through a mammoth effort, taking seven years to complete, students of the Bank under the leadership of Dick Backus have assembled this impressive compilation of information—covering the human history, geology, weather, physics, chemistry, biology, fisheries, and politics of Georges Bank. This marvelous book clearly represents a labor of love of the editors and more than 100 contributing authors, who come mainly from the Woods Hole scientific community.

The book is folio-sized (roughly 15 × 13″ page size) and will not fit conveniently on any bookshelf in my home; weighing in at about 10 pounds, it requires the sturdiest of coffee tables for display. It is richly produced, with many effective color graphics and well-reproduced photographs. The 57 chapters cover the physical sciences, biology, fisheries, and conflicting uses of Georges Bank. Interspersed among these relatively technical chapters are short marginalia and vignettes on such topics as how the Bank got its name, whether the shoals were ever dry, dory fishing, and fishing vessel profiles—all of which add a literary flair.

The editors went to great lengths to thoroughly and critically review all contributions, going so far as to list all reviewers at the end of the book. This results in overall high quality and even treatment among chapters. The first two chapters deal with the history of scientific exploration and cartography, a history that is

both colorful and fascinating. Photographs of legendary scientists reveal their personal sides, and the historical maps convey the slow process of discovery.

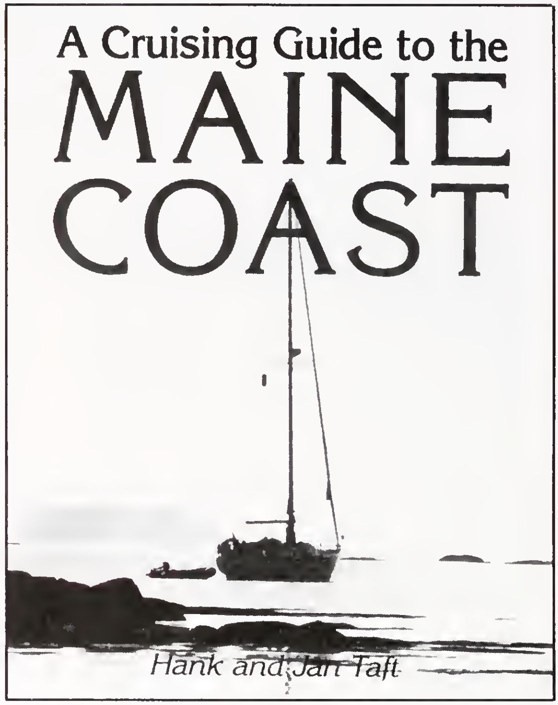
Of the chapters dealing with the natural sciences, I found those on geology and physical oceanography particularly well prepared and effective in explaining complex phenomena to the nonspecialist. Biology chapters contain numerous maps, showing the distribution patterns of invertebrates, fishes, seabirds, and marine mammals in the New England and Middle Atlantic regions. After laying a solid base by summarizing what is known, the section on fisheries concludes with a provocative appraisal of future management options. The concluding section on conflicting uses deals almost exclusively with offshore petroleum development and its possible effects on the marine ecosystem and fisheries resources.

The impetus for this treatise on Georges Bank was the controversy started by the Department of the Interior's 1974 proposal to lease tracts on the Bank for petroleum development. This controversy continues, despite the fact that the petroleum potential of the region is now viewed in considerably more bearish terms. In fact, the issue of Outer Continental Shelf (OCS) oil and gas development in areas such as New England, California, and Florida has assumed proportions of presidential politics in this election year.

It is ironic that the coalescence of such a comprehensive body of scientific information on Georges Bank was stimulated by the potential for offshore oil and gas exploration, when a compendium of this depth would be impossible for the region accommodating more than 90 percent of development of the U.S. OCS—the northwestern Gulf of Mexico. That region is a peer of Georges Bank as a rich fishery ground, but lacks the extensive database, history of sustained scientific investigation, and wealth of regional expertise that provide the foundation of the Georges Bank compendium. This book is the envy of my fellow Gulf scientists and the good fortune of New Englanders.

However, *Georges Bank* has appeal and use far beyond New England. It is the most comprehensive and thorough compendium ever assembled concerning a particular marine environment, anywhere in the world. It should serve as a model for similar efforts elsewhere. I highly recommend the treatise to a broad audience. The lay person interested in the sea, wherever he or she may be located, will find this a very instructive introduction to the contemporary understanding of the marine environment in a form that has considerable technical content, but made easily accessible and attractive to the reader. College teachers will find the book useful in conveying important principles by concrete example. Researchers will find a rich source of comparative information and short, stimulating expositions of cutting-edge issues in coastal oceanography. New Englanders will value the book as a table-top monument to the jewel that is the Georges Bank.

Donald F. Boesch
Executive Director
Louisiana Universities Marine Consortium



A Cruising Guide to the Maine Coast **by Hank and Jan Taft. 1988. International Marine Publishing Company, Camden, ME. 382 pp. + xiii. $35.00.**

This book is exactly what the title says, and a fair amount more. The authors, Hank and Jan Taft, descendents of President William Howard Taft, clearly have the requisite skills in writing, cruising, and organizing to put together a fine, well-written guide for the sailor going down east. As in other cruising guides, the authors acknowledge the assistance of many others, but what comes through is the evidence of their own personal experience.

The authors spent four years researching this book. This included making more than 500 anchorages—especially in every recommended hurricane hole, going up almost all the rivers, spending time in every significant harbor, and visiting the outlying islands. They report that their time in libraries and museums was as important as time on the water. It is this effort, I believe, that contributes to the book being more than just a cruising guide. Their practical advice on preparations, navigation, dealing with—or preventing—fouling lobster trap warps, and how to get assistance if in trouble, also adds to the completeness of the book.

I found the inclusion of two graphs in the

introductory section of particular interest. One shows foghorn operating hours at points along the coast during the months of May to September (summarizing 14 years of data). The other graph is of wind direction as a function of time of year. The discussion on navigating down east is most useful for the beginning cruising sailor, and a valuable reminder to the more experienced—as a recent, very sad account of the loss of an Alden schooner off Cape Ann shows (*WoodenBoat*, No. 83, August, 1988).

After the introductory and explanatory sections, a clear format is used to familiarize the cruising sailor with the points along the coast, geographically from west to east. Seven regions are defined and identified on the end sheet charts and upper corners of every page. Harbors are rated for beauty, protection, and facilities, using a five-point rating system and graphical symbols.

Each regional section begins with a double-page photograph (bled to the page edge, which makes turning to the section easy), and a chart showing the highly rated harbors in the region. One minor problem: on these charts, I had to get used to their not having identified the many other harbors, islands, coves, and bays discussed in the following text. In the text, the advice and information is superbly accurate, insofar as I can judge from my own, more limited, experience cruising this coast—right down to the fact that a retriever aboard shares everything with you, including lots of hair! There is usually an informative historic introduction to each harbor, river, or island. This adds immensely to one's enjoyment while reading (dreaming?), as well as while visiting. Illustrative chart excerpts are used frequently to clarify the text. The numerous contemporary photographs are beautiful, and often helpful.

After these introductions, details of the approaches and anchorages are given clearly and logically. This is perhaps *the* most valuable feature of this fine guide, for which I give the authors a "well done!" They even tell you how best to get ashore, what's there, and what are the nearby points of interest to cruising sailors. A number of natural history sidebars add information on coastal Maine wildlife, such as ospreys, gulls, terns, seals, eagles, loons, plus the delicious mussels. In these discussions, the authors are quite sensitive to the rights of others, and to the fragility of our environment. That they have the "wilderness ethic" is not surprising, since Hank is a trustee of Hurricane Island Outward Bound School, the Conservation Foundation, and the World Wildlife Fund, U.S. Jan's associations are more people-oriented, being a registered nurse and a trustee of Maine's Midcoast Mental Health.

I recommend this big (8¾" × 11¼") book to all cruising sailors who plan to sail along the coast of Maine; to those who have done so for many years; and even to those who may never make it down east, but like to dream. It is excellent reading, and full of valuable information and advice.

Paul Ferris Smith
Woods Hole, Massachusetts

Books Received

Biology

Axis and Circumference: The Cylindrical Shape of Plants and Animals by Stephen A. Wainwright. 1988. Harvard University Press, Cambridge, MA 02138. 132 pp. + viii. $22.95.

Culture of Science

Chaos: Making A New Science by James Gleick. 1987. Viking Penguin, New York, NY 10010. 352 pp. + xi. $19.95.

Explaining Science: A Cognitive Approach by Ronald N. Giere. 1988. The University of Chicago Press, Chicago, IL 60637. 321 pp. + xxi. $34.95.

Natural Obsessions: The Search for the Oncogene by Natalie Angier. 1988. Houghton Mifflin Company, Boston, MA 02108. 394 pp. + xv. $19.45.

The New Politics of Science by David Dickson. 1988. The University of Chicago Press, Chicago, IL 60637. 404 pp. + xi. $14.95.

Next: The Coming Era in Science edited by Holcomb B. Noble. 1988. Little, Brown, and Company, Boston, MA 02106. 190 pp. + xii. $17.95.

Thematic Origins of Scientific Thought: Kepler to Einstein by Gerald Holton. Revised edition, 1988. Harvard University Press, Cambridge, MA 02138. 499 pp. + vi. $25.00.

Diving

Code of Practice for Scientific Diving: Principles for the Safe Practice of Scientific Diving in Different Environments compiled and edited by the Scientific Committee of the Confédération Mondiale des Activités Subaquatiques. 1988. Unesco technical papers in marine science number 53, Unesco, Paris, France. 251 pp. + xvi. Free.

Microprocessor Applications to Multi-Level Air Decompression Problems by Karl E. Huggins. 1987. Michigan Sea Grant Publications, Ann Arbor, MI 48109. 32 pp. + viii. $5.00

Earth Science

Base Metal Sulfide Deposits in Sedimentary and Volcanic Environments edited by Günther H. Friedrich and Peter M. Herzig. 1988. Special Publication Number 5 of the Society for Geology Applied to Mineral Deposits, Springer-Verlag, Secaucus, NJ 07094. 290 pp. + viii. $65.50.

The Behavior of the Earth: Continental and Seafloor Mobility by Claude Allègre. 1988. Harvard University Press, Cambridge, MA 02138. 272 pp. + xii. $35.00.

The Climate of China and Global Climate edited by Ye Duzheng, Fu Congbin, Chao Jiping, and M. Yoshino. 1987. China Ocean Press/ Springer-Verlag, Secaucus, NJ 07094. 441 pp. + xv. $89.70.

Coral Reef Geomorphology by André Guilcher. 1988. Coastal Morphology and Research Series, John Wiley & Sons, New York, NY 10158. 228 pp. + xiii. $67.95.

Integral Transforms in Geophysics by Michael S. Zhdanov. 1988. Springer-Verlag, Secaucus, NJ 07094. 367 pp. + xxiii. $140.00.

Laboratory Exercises in Oceanography, Second Edition by Bernard W. Pipkin, Donn S. Gorsline, Richard E. Casey, and Douglas E. Hammond. 1987. W. H. Freeman and Company, New York, NY 10010. 257 pp. + x. $14.95.

Long and Short Term Variability of Climate edited by H. Wanner and U. Siegenthaler. 1988. Lecture Notes in Earth Sciences 16, Springer-Verlag, Secaucus, NJ 07094. 175 pp. $29.10.

New Perspectives in Basin Analysis edited by Karen L. Kleinspehn and Chris Paola. 1988. Frontiers in Sedimentary Geology, Springer-Verlag, Secaucus, NJ 07094. 453 pp. + xx. $64.00.

Tropical Rain Forests and the World Atmosphere edited by Ghillean T. Prance. 1987. AAAS Selected Symposium 101, Westview Press, Boulder, CO 80301. 105 pp. + xxi. $20.00.

Weather Systems by Leslie F. Musk. 1988. Cambridge University Press, New Rochelle, NY 10801. 160 pp. $19.95.

Environment

Chemistry and Biology of Solid Waste: Dredged Material and Mine Tailings edited by Wim Salomons and Ulrich Förstner. 1988. Springer-Verlag, Secaucus, NJ 07094. 305 pp. + x. $79.50.

Coastal Marine Ecosystems of Africa: Objectives and Strategy of the COMARAF Regional Project. 1988. Unesco reports in marine science 48, Unesco, Paris, France. 62 pp. + iii. Free.

Ecological Studies in the Middle Reach of Chesapeake Bay by Calvert Cliffs. 1987. Lecture Notes on Coastal and Esutarine Studies 23, Springer-Verlag, Secaucus, NJ 07094. 287 pp. + iv. $32.70.

Modeling Nature: Episodes in the History of Population Ecology by Sharon E. Kingsland. 1988. The University of Chicago Press, Chicago, IL 60637. 267 pp. + ix. $11.95.

Trace Elements in Environmental History edited by Gisela Grupe and Bernd Herrmann. 1988. Springer-Verlag, Secaucus, NJ 07094. 174 pp. + x. $41.00.

Field Guides

Marine Wildlife of Puget Sound, the San Juans, and the Strait of Georgia by Steve Yates. 1988. The Globe Pequot Press, Chester, CT 06412. 262 pp. $12.95.

Fisheries

Salmon Production, Management, and Allocation edited by William J. McNeil. 1988. Oregon State University Press, Corvallis, OR 97331. 194 pp. + xi. $29.95.

General Reading

Bertrand Russell by A. J. Ayer. 1988. The University of Chicago Press, Chicago, IL 60637. 168 pp. $9.95.

The Computer and the Mind: An Introduction to Cognitive Science by Philip N. Johnson-Laird. 1988. Harvard University Press, Cambridge, MA 02138. 444 pp. $29.50.

The Cosmic Blueprint: New Discoveries in Nature's Creative Ability To Order the Universe by Paul Davies. Simon & Schuster, New York, NY 10020. 223 pp. $17.95.

The Forest by David Bellamy. 1988. Our Changing World, Clarkson N. Potter Publishers, distributed by Crown Publishers, Avenel, NJ 07001. $9.95.

Industrial Policy of Japan edited by Ryutaro Komiya, Masahiro Okuno, and Kataro Suzumura. 1988. Academic Press, San Diego, CA 92191. 590 pp. + xv. $65.00.

Mathematics and the Unexpected by Ivar Ekeland. 1988. The University of Chicago Press, Chicago, IL 60637. 146 pp. + xiii. $19.95.

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The River by David Bellamy. 1988. Our Changing World, Clarkson N. Potter Publishers, distributed by Crown Publishers, Avenel, NJ 07001. $9.95.

The Water Planet: A Celebration of the Wonder of Water by Lyall Watson. 1988. Crown Publishers, New York, NY 10003. 206 pp. + x. $30.00.

Uncommon Wisdom: Conversations with Remarkable People by Fritjof Capra. 1988. Simon & Schuster, New York, NY 10020. 334 pp. $19.95.

History

Armada by Peter Padfield. 1988. Naval Institute Press, Annapolis, MD 21402. 208 pp. $24.95.

The Crest of the Wave: Adventures in Oceanography by Willard Bascom. 1988. Harper & Row, New York, NY 10022. 318 pp. + xiv. $19.95.

Geography, Technology, and War: Studies in the Maritime History of the Mediterranean, 649-1571 by John H. Pryor. 1988. Cambridge University Press, New Rochelle, NY 10801. 238 pp. + xviii. $34.50.

Marine Policy

A New Law of the Sea for the Caribbean: An Examination of Marine Law and Policy Issues in the Lesser Antilles edited by Edgar Gold. 1988. Lecture Notes on Coastal and Estuarine Studies 27, Springer-Verlag, Secaucus, NJ 07094. 276 pp. + xxii. $32.70.

East Coast Fisheries Law and Policy edited by Jill L. Bubier and Alison Rieser. 1987. Marine Law Institute, Portland, ME 04102. 482 pp. + xii. $25.00.

Ownership and Productivity of Marine Fishery Resources: An Essay on the Resolution of Conflict in the Use of the Ocean Pastures by Elmer A. Keen. 1988. McDonald & Woodward, Blacksburg, VA 24062. 122 pp. + xii. $10.95.

Wastewater Management for Coastal Cities: The Ocean Disposal Option edited by Charles C. Gunnerson. 1988. World Bank Technical Paper 77, The World Bank, Washington, DC 20433. 396 pp. + xxiv. $23.00.

Physical Science

Advances in Turbulence: Proceedings of the First European Turbulence Conference edited by G. Comte-Bellot and J. Mathieu. 1987. Springer-Verlag, Secaucus, NJ 07094. 586 pp. + xvi. $87.80.

Exploiting Remotely Sensed Imagery edited by K. A. Browning, B. J. Conway, J.-P. A. L. Muller, and D. J. Stanley. 1988. The Royal Society, London, England. 176 pp. + viii. £48.00.

Parameter Estimation and Hypothesis Testing in Linear Models by Karl-Rudolf Koch. 1988. Springer-Verlag, Secaucus, NJ 07094. 378 pp. + xvi. $49.50.

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Boatbuilding Manual: 3rd edition by Robert M. Steward. 1987. International Marine Publishing Company, Camden, ME 04843. 273 pp. + xii. $29.95.

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Pacific Sail: Four Centuries of Western Ships in the Pacific by Roger Morris. 1987. International Marine Publishing Company, Camden, ME 04843. 192 pp. $29.95.

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Shipmaster's Handbook On Ship's Business, Second Edition by James R. Aragon. 1988. Cornell Maritime Press, Centreville, MD 21617. 270 pp. + xii. $24.00.

World Cruising Routes by Jimmy Cornell. 1987. International Marine Publishing Company, Camden, ME 04843. 432 pp. + xvi. $29.95.

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U.S. Marine Sanctuaries

Vol. 31:1, Spring 1988—There are seven U.S. National Marine Sanctuaries protecting whales and seabirds, coral reefs, a Samoan bay, and a historic shipwreck—the *U.S.S. Monitor*. Additional sites have been proposed. Sanctuary science, policy, and education are addressed. A valuable reference for those interested in management of natural areas.

Caribbean Marine Science

Vol. 30:4, Winter 1987/88—A broad and inclusive view of the Caribbean Sea—its biology, mangrove ecology, and geology. Specific topics—climatic change, availability of marine resources, petroleum pollution, and new developments in fishing technology—are explored, and their impact on Caribbean coastal and island communities is examined.

Columbus, Plastics, Sea-Level Rise, TBT

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